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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Peter A. Hochstein	)	
Application No.: 09/382,702	)	TC Art Unit: 2838
Reissue Filed: August 24, 1999	)	Examiner: B. Vu
Original Patent: 5,661,645	)	
Issued: August 26, 1997	)	
For: POWER SUPPLY FOR LIGHT EMITTING DIODE ARRAY	) :	May 22, 2009

MAIL STOP APPEAL BRIEF – PATENTS
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

APPEAL BRIEF

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APPEAL BRIEF

I. REAL PARTY IN INTEREST

The real party in interest is Relume Corporation, by virtue of an assignment recorded in U.S. Patent and Trademark Office records at Reel 020835, Frame 0109.

II. RELATED APPEALS AND INTERFERENCES

The appellant is aware of no pending appeals, interferences, or other judicial proceedings.

As for prior related proceedings, an earlier notice of appeal dated November 3, 2003, was filed in the present application. Before the appeal was fully briefed, a request for continued examination was filed on January 16, 2007.

In addition, litigation involving U.S. Patent No. 5,661,645 (Evidence Appendix, Exhibit A), which the present application seeks to reissue, resulted in a judgment of invalidity of claims 1, 2, and 4-6 of the patent. *Relume Corp. v. Dialight Corp.*, 63 F.Supp.2d 788 (E.D. Mich. 1999), *aff'd*, 4 Fed. Appx. 893 (Fed. Cir. 2001) (Related Proceedings Appendix, Exhibit J). There is no pending litigation.

III. STATUS OF CLAIMS

Reissue claims 24, 28, 32, 37, 38, 41, 42, 44, and 46-53 are rejected and are appealed. Claims 24, 28, 32, and 44 are independent.

Claims 1-23 (all of the claims in original U.S. Patent No. 5,661,645), and reissue claims 25-27, 29-31, 33-36, 39, 40, 43, and 45, are canceled.

IV. STATUS OF AMENDMENTS

No claim amendments have been filed since the second rejection of the appealed claims in the office action of January 22, 2009, from which this appeal is taken.

The rejection being appealed was not made final. However, the application is ripe for appeal since the claims have been rejected twice. 37 C.F.R. § 41.31(a)(1).[1]

V. SUMMARY OF CLAIMED INVENTION

The claimed conflict monitor compatibility circuit provides safe and efficient operation of solid-state controlled vehicular and pedestrian traffic signals that have been retrofitted with LEDs.

A. Prior Art Traffic Signals

Prior art traffic signals include conflict monitor circuits as a safety feature to guard against hazards such as showing green lights at intersecting streets. This can happen if, say, a lightning strike creates a power surge that damages the signal's solid state traffic controller switch and results in conflicting green lights. The conflict monitor circuit detects the conflict and initiates remedial action, such as changing the green lights to a flashing red mode. Declaration of Peter A. Hochstein, dated April 12, 2007 (Evidence Appendix, Exhibit G; "the Hochstein Declaration"), para. 12; U.S. Patent No. 5,075,601 to Hildebrand (Evidence Appendix, Exhibit C) col. 1, lines 11-33).

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1. Dependent claims 46-53 were not acted on in the penultimate office action of August 12, 2008. Consequently, the rejection of all of the claims in the last office action, mailed January 22, 2009, was not made final, even though no claim had been amended in response to the earlier office action.

Because LEDs consume so little electrical power, they are being retrofitted to existing traffic signals with older forms of illumination, such as incandescent bulbs. Specification col. 1, line 62, to col. 2, line 4. (Specification citations are to columns and line numbers of the applicant's original U.S. Patent No. 5,661,645.) The conventional power supply components of these signals remain in place even though the light source has been replaced with LEDs. For example, in addition to the applicant's new conflict monitor comparability circuit (discussed further below), independent claims 24, 28, and 32 include these conventional components:

- an electrical input for coupling to a source of a.c. line voltage through a solid state traffic controller switch for providing an electrical input voltage having an operating range with a lower limit voltage sufficient to activate the LEDs when the switch is on; specification col. 5, lines 15-18, col. 6, lines 27-30, Figs. 5, 6a, 6b (describing an electrical input 22 coupled to an a.c. power main through a solid state switch; Fig 6a was amended, Evidence Appendix, Exhibit F).
- a rectifier coupled to the electrical input and having a rectifier output; specification col. 5, lines 35-39, Fig. 5 (the rectifier 32).
- a line voltage regulating switchmode power supply having a power supply input coupled to the rectifier output and a power supply output; specification col. 5, lines 41-54, Fig. 5 (the power supply 38).
- a plurality of LEDs coupled to the power supply output for emitting light in response to the power supply output; specification col. 5, lines 5-10, col. 6, lines 24-27, Fig. 5 (the LEDs 16).

Older conflict monitor circuits for signals using conventional power supply components can cause false conflict detection when used with LEDs. The claimed invention relates to a conflict monitor compatibility circuit that solves this problem and still maintains the low power consumption advantage of LEDs. Hochstein Declaration, para. 12.

False conflict indications can occur because of a difference between the electrical characteristics of LEDs and incandescent lamps. When power to an incandescent lamp is off, it exhibits a relatively low resistance (impedance). When the lamp is on, it presents a high resistance to the circuit, resulting in an elevated voltage. A properly operating conflict monitor circuit detects when the voltages associated with crossing streets' green lights exceed a predetermined value, indicating that the green lights for both streets are on at the same time. The conflict monitor circuit then takes safety measures such as changing the green signals to an all flashing red mode. Hochstein Declaration, para. 13.

LEDs are different because, unlike incandescent lamps, they typically exhibit a relatively high input impedance in the presence of even low currents, such as normal leakage currents from the signal's solid state traffic controller switch when it is turned off. Leakage currents do not cause a problem with incandescent lamps because of incandescent lamps' relatively low impedance at these low leakage currents. But LEDs' high impedance can create appreciable voltage levels when the traffic control switch is turned off. So when LEDs are retrofitted to conventional traffic signals, conflict monitor circuits that use elevated voltages to indicate a conflict ("on" green lights at crossing streets) can erroneously detect conflicts even if

the traffic controller switch is functioning properly. This is because leakage currents, which are present during normal operation of the solid state traffic controller, are not shunted from the conflict monitor circuit by LEDs as they would be by incandescent lamps. In other words, an LED signal subjected to leakage currents can create a high voltage, which the conflict monitor circuit wrongly interprets as a lighted LED. See specification col. 5, lines 15-30; Hildebrand col. 1, lines 11-33; Hochstein Declaration, para. 14.

There were solutions to this false positive problem before the applicant's new conflict monitor compatibility circuit. However, none of them enabled full advantage to be taken of the low power consumption of LEDs as compared to other types of illuminating devices such as incandescent lamps or luminescent (neon or fluorescent) lights.

One solution was placing a large capacitor across the inputs to the LEDs to absorb leakage currents. This defeated the purpose of using LEDs for their low power consumption because of the reactive power drawn by the capacitor. See specification col. 5, lines 23-30. Another solution is described in Hildebrand, which was used to reject the applicant's claims. But as discussed below in the "Argument" section, Hildebrand's "dynamic load circuit" also mitigates the advantages of using LEDs in the first place.

B. Applicant's Added Conflict Monitor Compatibility Circuit

The claimed invention introduces a new circuit, called a conflict monitor compatibility circuit, having the following features (independent claim 44 recites the elements in a slightly different order, but contains the same limitations):

Claimed circuit	Disclosed Embodiment
a low impedance load and a transistor in series connection with the low impedance load,	A circuit 24 to "eliminate problems with conflict monitors" includes a low impedance resistor 60 connected in series with a transistor Q2. Col. 6, lines 36-42, 57-62, col. 7, lines 12-15, 44-50; Figs. 6a, 6b.
the transistor being biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is at or above the operating range lower limit voltage and	The bipolar transistor switch Q2 is off ("essentially nonconductive") whenever the traffic controller switch is on to provide the nominal 120 volts (with a range of 85-140 volts) at the electrical input 22 so that a Zener diode D5 reverse-conducts from cathode to anode. Col. 6, lines 27-30, col. 7, lines 44-46, 63-67.
an essentially conductive condition if the electrical input voltage drops to a predetermined value below the operating range lower limit voltage, wherein:	The transistor Q2 is on ("essentially conductive") if the electrical input 22 drops below 40 volts (lower than the 85-140 volt operating range) and prevents the Zener diode D5 from conducting in the reverse direction. Col. 7, lines 41-47, 53-60.
the transistor in the essentially nonconductive condition prevents dissipation of power from the power supply output through the low impedance load whenever the electrical input voltage is within the operating range, and	When the transistor Q2 is off, the resistor 60 is removed from the circuit, "thereby preventing unnecessary dissipation of power." Col. 7, line 65, to col. 8, line 1.
the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.	"If the Zener diode D5 does not conduct, the transistor Q2 is turned on to place the load resistor 60 [in] the power lines 22 causing the leakage voltage [from the solid state switch] to drop below 10 volts." Col. 7, lines 18-30, 47-48, 59-62.

As the claims state, the applicant's conflict monitor compatibility circuit includes a transistor biased as a switch. This means that the claimed

series-connected low impedance load is out of the circuit (the transistor is in the essentially nonconductive condition) whenever the electrical input voltage is within its operating range. If the electrical input voltage drops below a predetermined value lower than the operating range, the low impedance load is coupled to the electrical input (the transistor is in the essentially conductive condition).

The principle is that an electrical input voltage below a predetermined value indicates that the solid state traffic controller switch is actually off and that the sensed voltage is due to leakage currents. The transistor is turned on to couple the low impedance load to the electrical input and reduce the leakage voltage to a value that is consistent with proper operation of the conflict monitor circuit (say 10 volts; see specification col. 7, lines 47-48). Fig. A shows the Fig. 6b embodiment in this mode:

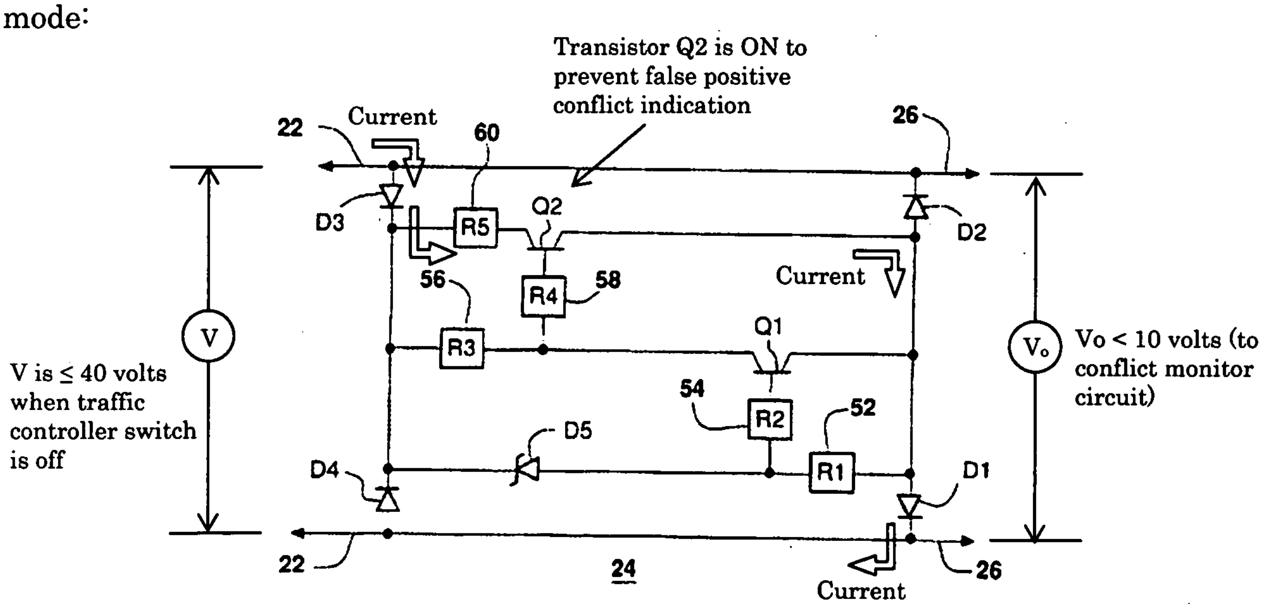

FIG. A

Shunting the leakage current through the low impedance load in this manner enables proper operation of the conflict monitor circuit because the artificially

elevated leakage voltage cannot trigger a false conflict. That is, the conflict monitor circuit will detect a low voltage, just as it would if the traffic signal used incandescent lamps. This prevents false positive conflict indications due solely to normal leakage currents. Hochstein Declaration, para. 17.

Stepping back a moment, it is important to keep in mind that the applicant's claimed conflict monitor compatibility circuit does not differ materially from Hildebrand's "dynamic load circuit" in how it avoids these false positive indications. That is, when the solid state traffic controller switch is off, both circuits shunt leakage currents through a low impedance load.

But when the traffic controller switch is on, the applicant's circuit improves markedly over Hildebrand. Fig. B shows the applicant's Fig. 6b embodiment in this mode:

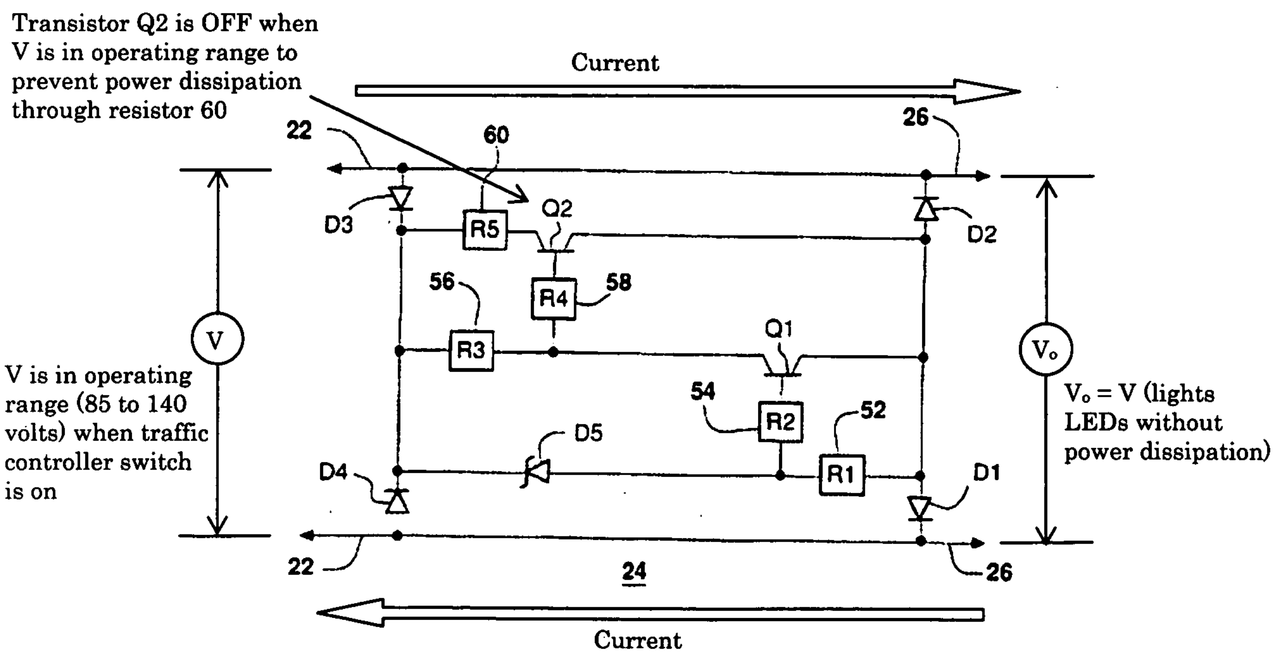

FIG. B

Unlike Hildebrand's circuit, the applicant's circuit, in the words of claim 24, "prevents dissipation of power from the power supply output through the low impedance load whenever the electrical input voltage is within the operating range." This is because the transistor is off whenever the solid state traffic controller switch is on, with the electrical input voltage in its operating range. This ensures that the signal consumes only the power required to illuminate the LEDs.

None of the claims includes means plus function or step plus function limitations under 35 U.S.C. § 112, sixth paragraph (Claims Appendix).

VI. GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL

A. Claim 24 (and its dependent claims) are rejected as being unpatentable under 35 U.S.C. § 103(a) over U.S. Patent No. 5,463,280 to Johnson (Evidence Appendix, Exhibit B), in view of Applicant Prior Art and further in view of Hildebrand (Evidence Appendix, Exhibit C).

B. Claims 28 and 32 (and their respective dependent claims) are rejected as being unpatentable under 35 U.S.C. § 103(a) over Johnson, in view of the Brown, M., Power Supply Cookbook, Motorola (1994) (Evidence Appendix, Exhibit D) and the Motorola Data Sheet for Power Factor Controller MC34261 (Evidence Appendix, Exhibit E), in view of Applicant Prior Art and further in view of Hildebrand.

C. Claim 44 (and its dependent claims) are rejected as being unpatentable under 35 U.S.C. § 103(a) over Johnson in view of Hildebrand.

VII. ARGUMENT

For purposes of this appeal, all claims will stand or fall with claim 24.[2]

A. Claim 24 and Its Dependent Claims

1. The Claimed Invention is Patentable Over the Prior Art

The rejection relies on Johnson as disclosing claim 24's a.c. input, rectifier, and switchmode power supply (*supra*, page 3), as well as limitations in the dependent claims. "Applicant's prior art" is relied on as a concession that traffic signals retrofit with LEDs are in the prior art, along with certain limitations in other dependent claims. For purposes of this appeal, the applicant does not contest those aspects of the rejection.

After asserting that the prior art includes those claim features, the examiner summarizes his reading of Hildebrand:

> Johnson in view of Applicant's Prior Art (APA) discloses the claimed invention . . . except for the use of a conflict monitor circuit used to help control leakage currents by providing high impedance if such conditions exist.
>
> Hildebrand discloses that it is known in the art to provide the use of conflict monitor circuit used to help control leakage currents by providing high impedance if such conditions exist.

Office action mailed January 22, 2009, at 5.

This appeal turns on whether Hildebrand would have suggested the claimed conflict monitor compatibility circuit to one of ordinary skill in the art.

Initially, the examiner's explanation of Hildebrand's circuit betrays a lack of understanding of the respective circuits in Hildebrand and the appealed claims. The

2. The applicant does not mean to imply that the other appealed claims, including the dependent claims, may not also be patentable in their own right.

examiner says that Hildebrand discloses and the applicant claims "a conflict monitor circuit used to help control leakage currents by providing high impedance if such conditions exist." This is exactly backwards.[3] Both the applicant's and Hildebrand's circuits shunt leakage currents through a low impedance load in the presence of leakage currents:

> Claim 24: the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.
>
> Hildebrand: the dynamic load circuit achieves its desired purpose of insuring that the power supply presents a low impedance to the line power when the power is off, so that external alternating current switch leakage current cannot create appreciable voltages at the input terminals. Col. 6, lines 60-65.

But more importantly, how Hildebrand and the applicant handle leakage currents when the traffic controller switch is <u>off</u> is beside the point, because the focus here is what happens when the switch is <u>on</u>. That is how the applicant's claimed circuit differs, significantly, from Hildebrand's.

The following limitations in claim 24 are the heart of this appeal:

> the transistor [in series connection with the low impedance load] being biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is at or above the operating range lower limit voltage . . . , wherein:
>
> the transistor in the essentially nonconductive condition prevents dissipation of power from the power supply output through the low impedance load whenever the electrical input voltage is within the operating range . . . .

3. The examiner also insists on calling the applicant's circuit a "conflict monitor circuit." The applicant claims a "conflict monitor <u>compatibility</u> circuit," which makes retrofit LED traffic signals compatible with conflict monitor circuits designed for other types of illumination devices.

Hildebrand's circuit falls short when the input voltage is within the operating range (as claimed, a voltage "sufficient to activate the LEDs"). The examiner equated Hildebrand's resistor R7 with the applicant's claimed "low impedance load." Office action mailed January 22, 2009, at 5-6. But rather than taking the resistor R7 out of the circuit by virtue of its series connection with a switch-biased transistor, Hildebrand's resistor R7 remains in the circuit and permits dissipation of significant power at operating input voltages.

This property of Hildebrand's circuit is seen in Exhibit B to the Hochstein Declaration. The second plot in Hochstein Declaration Exhibit B shows that at the lower end of an LED's operating range (say, 85 volts), the Hildebrand circuit dissipates about 4 watts of power. The same plot shows the marked contrast provided by a conflict monitor compatibility circuit in accordance with the applicant's claim 24, which dissipates only about 0.2-0.3 watts at the same voltage. Claim 24 reflects this advantage by reciting that the claimed circuit "prevents dissipation of power from the power supply output through the low impedance load whenever the electrical input voltage is within the operating range."

The amount of power dissipated by Hildebrand's dynamic load circuit makes it particularly unsuitable for use with LEDs. For example, even at a nominal LED operating voltage of 115-120 volts, Hildebrand's circuit consumes about 2.4 watts as compared to about 0.3 watts for the applicant's claimed circuit. Recent LED traffic signals are rated as low as 6 watts. Hochstein Declaration, para. 26 and Exhibit C.

Hildebrand's wasted 2.4 watts is a significant fraction of the entire amount of power needed to operate the LEDs.

The claimed structure that achieves this advantage over Hildebrand is a transistor "biased as a switch having an essentially <u>nonconductive</u> condition whenever the electrical input voltage is at or above the operating range lower limit voltage." In contrast, Hildebrand's MOSFET amplifier Q3, likened by the Examiner to the applicant's claimed transistor biased as a switch, office action mailed January 22, 2009, at 5-6, is <u>conductive</u> at and above the lower limit of a voltage operating range sufficient to activate LEDs. This is shown in the first plot in Hochstein Declaration Exhibit B, which compares the current through the applicant's claimed low impedance load to the current through Hildebrand's resistor R7. Hochstein Declaration, para. 25. That plot establishes that a circuit in accordance with Hildebrand's disclosure conducts about 53 milliamps at the lower limit of a typical LED operating voltage range, while the applicant's switch-biased transistor limits the wasted current to a virtual-zero three milliamps at the same voltage.

Nor would one of ordinary skill in the art have had any reason at the time of the invention to substitute a switch-biased transistor having the claimed operational properties for Hildebrand's MOSFET amplifier Q3. Hildebrand's dynamic load circuit is used with luminescent tube lamp traffic signals. Hildebrand col. 1, lines 11-33, and col. 6, lines 66-68. The 2.4 watts dissipated through Hildebrand's resistor R7 is a small fraction of the power consumed by luminescent tubes, so there would have been no reason for one ordinarily skilled in the art to

seek a way to reduce what is a minimal amount of wasted power for a luminescent tube signal. Hochstein Declaration, para. 27.

Accordingly, claim 24 is patentable and the rejection should be reversed.

2. The Examiner Did Not Address Applicant's Claims or Evidence

The applicant has had to take this appeal without having the benefit of the examiner's comments on how Hildebrand was applied to the actual claim language or why the examiner did not find the Hochstein Declaration persuasive.

Claims very similar to those on appeal were presented in a Preliminary Amendment dated April 13, 2007 (following a request for continued examination dated January 16, 2007). The Hochstein Declaration accompanied the Preliminary Amendment. Those claims were rejected in an office action mailed July 16, 2007. The office action referred to the "claimed clamp circuit's 'voltage sensing means'" and a "control load means," features that had been in original patent claim 6. The claims under examination had no "clamp circuit," no "voltage sensing means," and no "control load means." The office action also referred to language concerning canceled patent claim 6 in the court's opinion in *Relume Corp. v. Dialight Corp.* The office action did not mention the Hochstein Declaration.

In an Amendment dated December 12, 2007, the applicant amended the claims to their present form. The Amendment also requested that the examiner treat the claim language actually presented and noted the differences between the reissue claims in this appeal and patent claim 6, which had been held invalid by the court (more about which later).

The result was allowance of the application (although still without mention of the Hochstein Declaration), with an examiner's statement of reasons for allowance:

> None of the prior art alone or in combination discloses based on applicant's arguments in the response "a conflict monitor compatibility circuit achieves this advantage over Hildebrand (prior art) by using a transistor "biased as a switch having an essentially **nonconductive** condition whenever the electrical **input voltage is at or above the operating range lower limit voltage.**" Hildebrand's MOSFET Q3, likened by the Examiner to the applicant's transistor biased as a switch **is conductive at and above the lower limit of a voltage operating range sufficient to activate LEDs.**

Notice of Allowability, mailed February 11, 2008 (emphasis in original)

After the applicant paid the issue fee, the PTO withdrew the application from issue. In an ensuing office action, mailed August 12, 2008, original patent claims 7-23 were rejected (they had been allowed fairly early in the prosecution) over new prior art. The reissue claims, which have not been amended since their allowance, were rejected under reasoning nearly identical to that in the pre-allowance office action. (The examiner's comments on Hildebrand were taken *verbatim* from the previous office action.) As in the previous office action, the examiner referred to the "[nonexistent] claimed clamp circuit's [nonexistent] 'voltage sensing means'" and a "[nonexistent] control load means," and again referred to language concerning patent claim 6 in *Relume Corp. v. Dialight Corp.* Still the examiner did not mention the Hochstein Declaration. Nor did he explain why he changed his position expressed in his statement of reasons for allowance.

The applicant's Response to Office Action dated September 12, 2007, canceled patent claims 7-23. The applicant again requested that the examiner treat the actual claim language and discuss the Hochstein Declaration. The next office action,

which is the subject of this appeal, again referred to the "claimed clamp circuit's 'voltage sensing means'" and the "control load means." There was no mention of the Hochstein Declaration.

If the examiner had considered the Hochstein Declaration, he could not have repeatedly made the following erroneous statement regarding Hildebrand:

> Then finally, the [Hildebrand] circuit when the traffic light is off, thereby preventing leakage current and that <u>it completely removes this resistor (R7) from the circuit when the light is on</u>.

Office action mailed July 16, 2007, at 4, 6, and 8; office action mailed August 12, 2008, at 13; office action mailed January 22, 2009, at 3, 6, and 7-8 (emphasis supplied).

Hildebrand Fig. 4 shows that the MOSFET transistor Q3, unlike the claimed "transistor biased as a switch," is conductive at voltages within the operating range of an LED. In addition, the Hochstein Declaration reports tests conducted using the circuit disclosed in Hildebrand. Those tests bear out that at such voltages Hildebrand's resistor R7 remains very much in the circuit, drawing current and dissipating power. Hochstein Declaration, para. 26 and Exhibit B.

From the court's opinion in *Relume Corp. v. Dialight Corp.*, the examiner quotes the portion relating to the applicability of Hildebrand to claim 6 of original U.S. Patent 5,661,645. The claims now presented are very different from claim 6 of the original patent. It is self-evident that the findings of the court relative to canceled patent claim 6 are, at best, of limited probative value in determining the patentability of the reissue claims now under consideration.

The applicant now claims a conflict monitor compatibility circuit, rather than original claim 6's "adaptive clamp circuit means" with "voltage sensing means" and a "controlled load means." Among the features of the applicant's reissue claims missing from patent claim 6 are an "electrical input voltage having an operating range with a lower limit voltage sufficient to activate the LEDs," a "transistor . . . biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is at or above the operating range lower limit voltage," and the operational characteristic wherein "the transistor in the essentially nonconductive condition prevents dissipation of power from the power supply output through the low impedance load whenever the electrical input voltage is within the operating range." At least these claim limitations distinguish the applicant's invention over Hildebrand, and none of them are discussed in the court's opinion.

The examiner relies particularly on the court's finding that "[w]hen the Hildebrand light is on, its dynamic load circuit removes the resistor (R7) [from the circuit]." Office action mailed January 22, 2009, at 6. This is true only so far as the resistor is removed when the applied voltage is 140 v.a.c. (See the far right end of the first plot of Exhibit B of the Hochstein Declaration, where the current through the resistor is almost as low as the level obtained by the applicant's claimed circuit.) However, as shown in this plot and discussed above, Hildebrand's resistor R7 is not removed from the circuit "<u>whenever</u> the electrical input voltage is at or above the operating range lower limit voltage [sufficient to activate an LED]." Thus, the court's opinion in fact has no bearing on the patentability of the present claims.

Finally, the court suggests that its conclusion concerning the invalidity of claim 6 might have been different if the claim had recited the reduced power dissipation achieved by the applicant's circuit. 63 F.Supp.2d at 825. In contrast, claim 24 does recite the prevention of power dissipation as a feature of the applicant's conflict monitor compatibility circuit.

B. Claims 28 and 32 and Their Dependent Claims

For purposes of this appeal, these claims will stand or fall with claim 24.

C. Claim 44 and Its Dependent Claims

For purposes of this appeal, these claims will stand or fall with claim 24.

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CLAIMS APPENDIX

24. A power supply assembly for powering light emitting diodes (LEDs) in an outdoor line-connected signal, comprising:

an electrical input for coupling to a source of a.c. line voltage through a solid state traffic controller switch for providing an electrical input voltage having an operating range with a lower limit voltage sufficient to activate the LEDs when the switch is on;

a rectifier coupled to the electrical input and having a rectifier output;

a line voltage regulating switchmode power supply having a power supply input coupled to the rectifier output and a power supply output;

a plurality of LEDs coupled to the power supply output and having multiple current paths for emitting light in response to the power supply output; and

a conflict monitor compatibility circuit including a low impedance load and a transistor in series connection with the low impedance load, the transistor being biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is at or above the operating range lower limit voltage and an essentially conductive condition if the electrical input voltage drops to a predetermined value below the operating range lower limit voltage, wherein:

the transistor in the essentially nonconductive condition prevents dissipation of power from the power supply output through the low impedance load whenever the electrical input voltage is within the operating range, and

the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.

28. A power supply assembly for powering light emitting diodes (LEDs) in an outdoor line-connected signal, comprising:

an electrical input for coupling to a source of a.c. line voltage through a solid state traffic controller switch for providing an electrical input voltage having an operating range with a lower limit voltage sufficient to activate the LEDs when the switch is on;

a rectifier coupled to the electrical input and having a rectifier output;

a switchmode power supply for maintaining current and voltage waveforms substantially in phase and for providing a regulated current output with respect to variations in the input line voltage, the power supply having a power supply input coupled to the rectifier output and a power supply output;

a plurality of LEDs coupled to the power supply output and having multiple current paths for emitting light in response to the power supply output; and

a conflict monitor compatibility circuit including a low impedance load and a transistor in series connection with the low impedance load, the transistor being biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is at or above the operating range lower limit voltage and an essentially conductive condition if the electrical input voltage drops to a predetermined value below the operating range lower limit voltage, wherein:

the transistor in the essentially nonconductive condition prevents dissipation of power from the power supply output through the low impedance load whenever the electrical input voltage is within the operating range, and

the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.

32. A power supply assembly for powering light emitting diodes (LEDs) in an outdoor line-connected signal, comprising:

an electrical input for coupling to a source of a.c. line voltage through a solid state traffic controller switch for providing an electrical input voltage having an operating range with a lower limit voltage sufficient to activate the LEDs when the switch is on;

a rectifier coupled to the electrical input and having a rectifier output;

a switchmode power supply for improving poor power factor, whereby the power supply provides essentially constant current at a power supply output with respect to variations in line voltage input, and whereby current and voltage waveforms are maintained substantially in phase, the power supply having a power supply input coupled to the rectifier output and a power supply output;

a plurality of LEDs coupled to the power supply output and having multiple current paths for emitting light in response to the power supply output; and

a conflict monitor compatibility circuit including a low impedance load and a transistor in series connection with the low impedance load, the transistor being

biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is at or above the operating range lower limit voltage and an essentially conductive condition if the electrical input voltage drops to a predetermined value below the operating range lower limit voltage, wherein:

the transistor in the essentially nonconductive condition prevents dissipation of power from the power supply output through the low impedance load whenever the electrical input voltage is within the operating range, and

the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.

37. The assembly according to claim 24, 28 or 32 wherein the switchmode power supply comprises an integrated circuit power supply.

38. The assembly of claim 37 wherein the integrated circuit power supply comprises a power factor correcting switchmode converter integrated circuit.

41. The assembly according to claim 24, 28 or 32 wherein the plurality of LEDs comprise a plurality of series-parallel connected LEDs arranged in strings.

42. The assembly according to claim 41 wherein the plurality of LEDs comprise a ballast resistor in each string.

44. A conflict monitor compatibility circuit for use in traffic and pedestrian signaling applications, comprising:

a plurality of LEDs for emitting light in response to an electrical input adapted to be coupled to a source of a.c. line voltage through a solid state traffic controller switch for providing an electrical input voltage having an operating range with a lower limit voltage sufficient to activate the LEDs when the switch is on;

a transistor biased as a switch that has an essentially nonconductive condition whenever the electrical input voltage is at or above the operating range lower limit voltage and an essentially conductive condition if the electrical input voltage drops to a predetermined value below the operating range lower limit voltage; and

a low impedance load in series connection with the transistor, wherein:

the transistor in the essentially nonconductive condition prevents dissipation of power through the low impedance load whenever the electrical input voltage is within the operating range, and

the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.

46. The assembly according to claim 24, 28, or 32, wherein the conflict monitor compatibility circuit further includes a sensor for providing a control output if the electrical input voltage drops below the predetermined value and a control element for switching the transistor to the essentially conductive condition in response to the control output.

47. The assembly according to claim 46, wherein the sensor is a Zener diode that conducts in a reverse direction only at voltages above the predetermined value.

48. The assembly according to claim 47, wherein the control element is a second transistor biased as a switch and having a base coupled to the Zener diode.

49. The assembly according to claim 24, 28, or 32, further comprising an electromagnetic interference filter coupled to the power supply for preventing conducted interference from feeding back onto the a.c. line.

50. The assembly according to claim 24, 28, or 32, further comprising a traffic, pedestrian or rail crossing signal housing enclosing the assembly.

51. The conflict monitor compatibility circuit according claim 44, further comprising a sensor for providing a control output if the electrical input voltage drops below the predetermined value and a control element for switching the transistor to the essentially conductive condition in response to the control output.

52. The conflict monitor compatibility circuit according to claim 51, wherein the sensor is a Zener diode that conducts in a reverse direction only at voltages above the predetermined value.

53. The conflict monitor compatibility circuit according to claim 52, wherein the control element is a second transistor biased as a switch and having a base coupled to the Zener diode.

EVIDENCE APPENDIX

Sources of Exhibits A-I (37 C.F.R. § 41.37(c)(1)(ix):

Exhibit A is the patent which the present application seeks to reissue.

Exhibits B-E are the references relied on to reject the appealed claims.

Exhibit F is Fig. 6a of original U.S. Patent No. 5,661,645, incorporating the amendment approved by the examiner in the communication mailed April 28, 2008.

Exhibit G (which includes its own Exhibits A-C) was submitted in a Preliminary Amendment dated April 12, 2007, following a request for reexamination dated January 16, 2007. The examiner never referred to this Declaration in any subsequent paper.

Exhibit H is a copy of a return postcard (front and back) from the applicant's attorney's file establishing that the Declaration of Peter A. Hochstein, dated April 12, 2007, with its Exhibits A-C, was received by the USPTO on April 13, 2007.

Exhibit I is a printout of the image file wrapper of the present application from the USPTO's Patent Application Information and Retrieval system establishing that Exhibit G was entered in the file of the application on April 13, 2007.

RELATED PROCEEDINGS APPENDIX

EXHIBIT J .... *Relume Corp. v. Dialight Corp.*, 63 F.Supp. 788 (E.D. Mich. 1999), *aff'd*, 4 Fed. Appx. 893 (Fed. Cir. 2001)

EXHIBIT A

US005661645A

United States Patent [19]

Hochstein

[11] Patent Number: 5,661,645

[45] Date of Patent: Aug. 26, 1997

[54] POWER SUPPLY FOR LIGHT EMITTING DIODE ARRAY

[76] Inventor: Peter A. Hochstein, 2966 River Valley Dr., Troy, Mich. 48098

[21] Appl. No.: 673,200

[22] Filed: Jun. 27, 1996

[51] Int. Cl.^{6} H02M 5/42

[52] U.S. Cl. 363/89

[58] Field of Search 363/80, 89, 126

[56] References Cited

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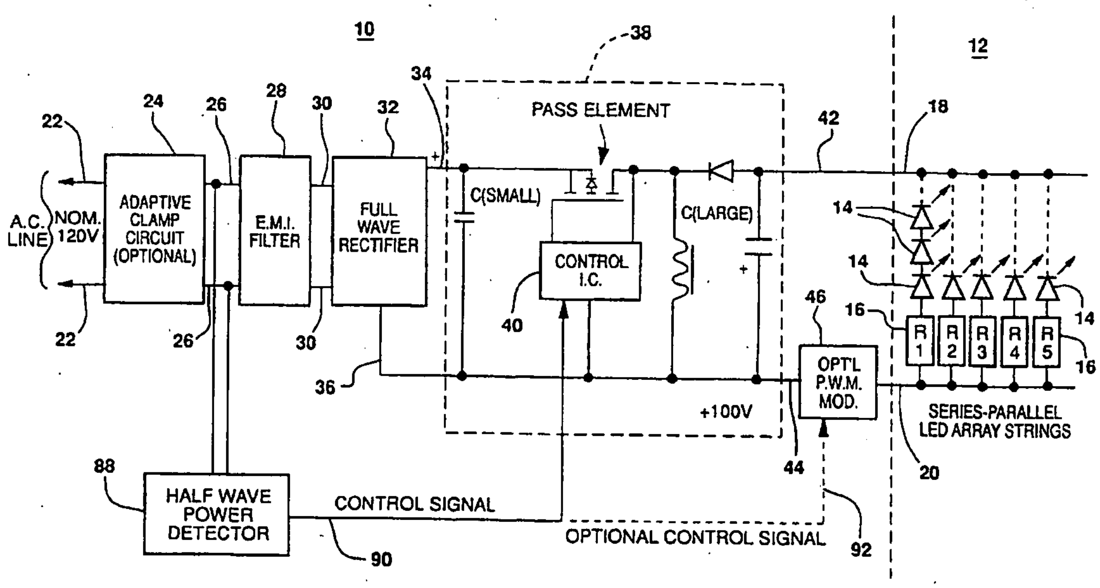
Primary Examiner—Stuart N. Hecker
Attorney, Agent, or Firm—Howard & Howard

[57] ABSTRACT

An apparatus (10) for supplying regulated voltage d.c. electrical power to an LED array (12) includes a rectifier (32) responsive to a.c. power for generating rectified d.c. power and a power factor correcting and voltage regulating buck/boost switchmode converter (38) responsive to the rectified d.c. power for generating regulated voltage d.c. power to illuminate the LED array (12). A battery backup system (62) receives the a.c. power applied to the rectifier (32) for charging a rechargeable battery (66) and sensing an a.c. power failure. A switch-over relay (82) is connected between the battery backup system (62) and the rectifier. Upon sensing a failure of the a.c. power, the battery backup system (62) controls the switch-over relay (82) to connect the battery backup system (62) to the rectifier (32) to provide d.c. power to the switchmode converter (38) to illuminate the LED array (12). A half wave power detector (88) causes the apparatus (10) to reduce regulated d.c. power to dim the LED array (12).

23 Claims, 6 Drawing Sheets



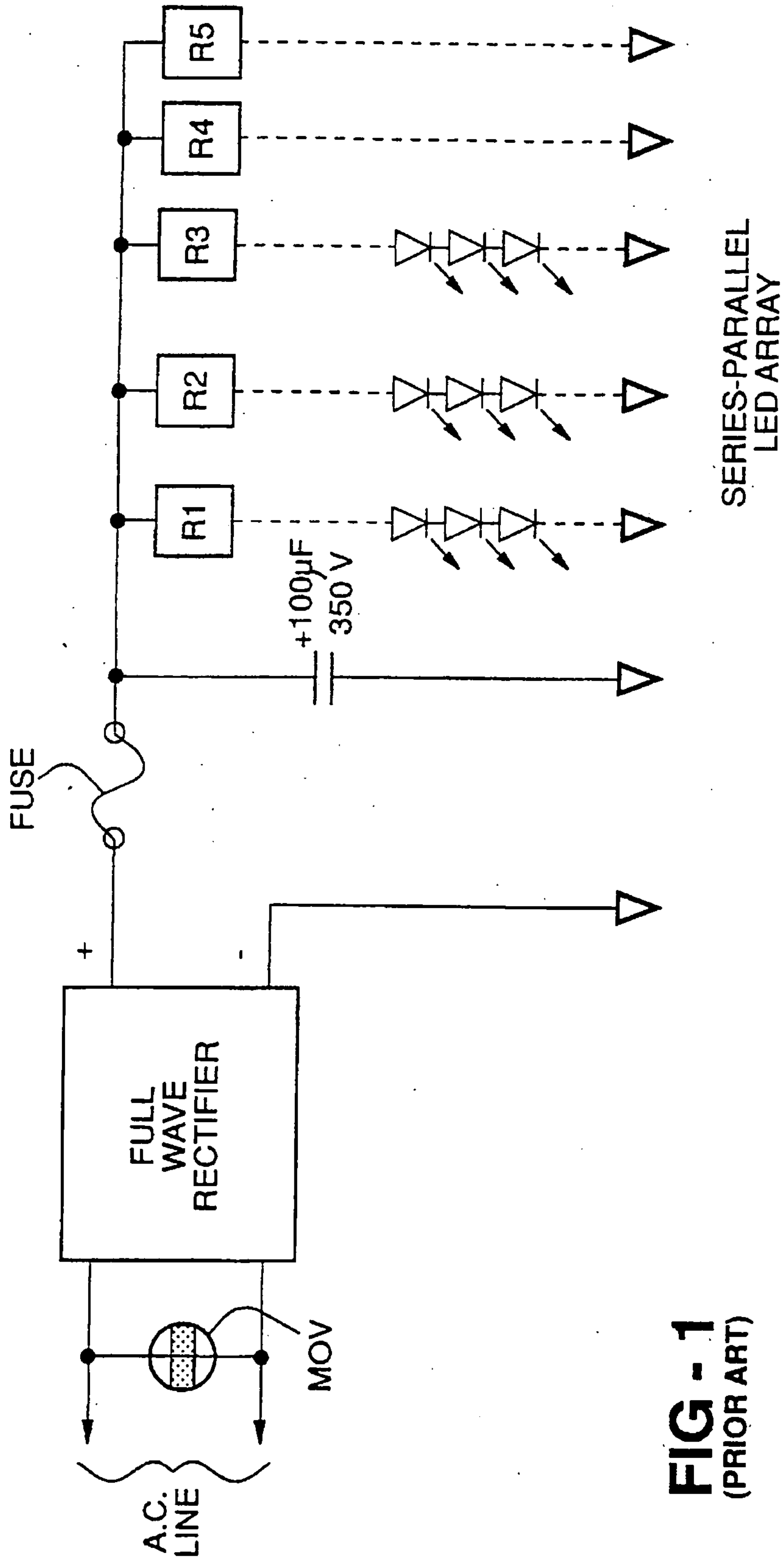


FIG - 1 (PRIOR ART)

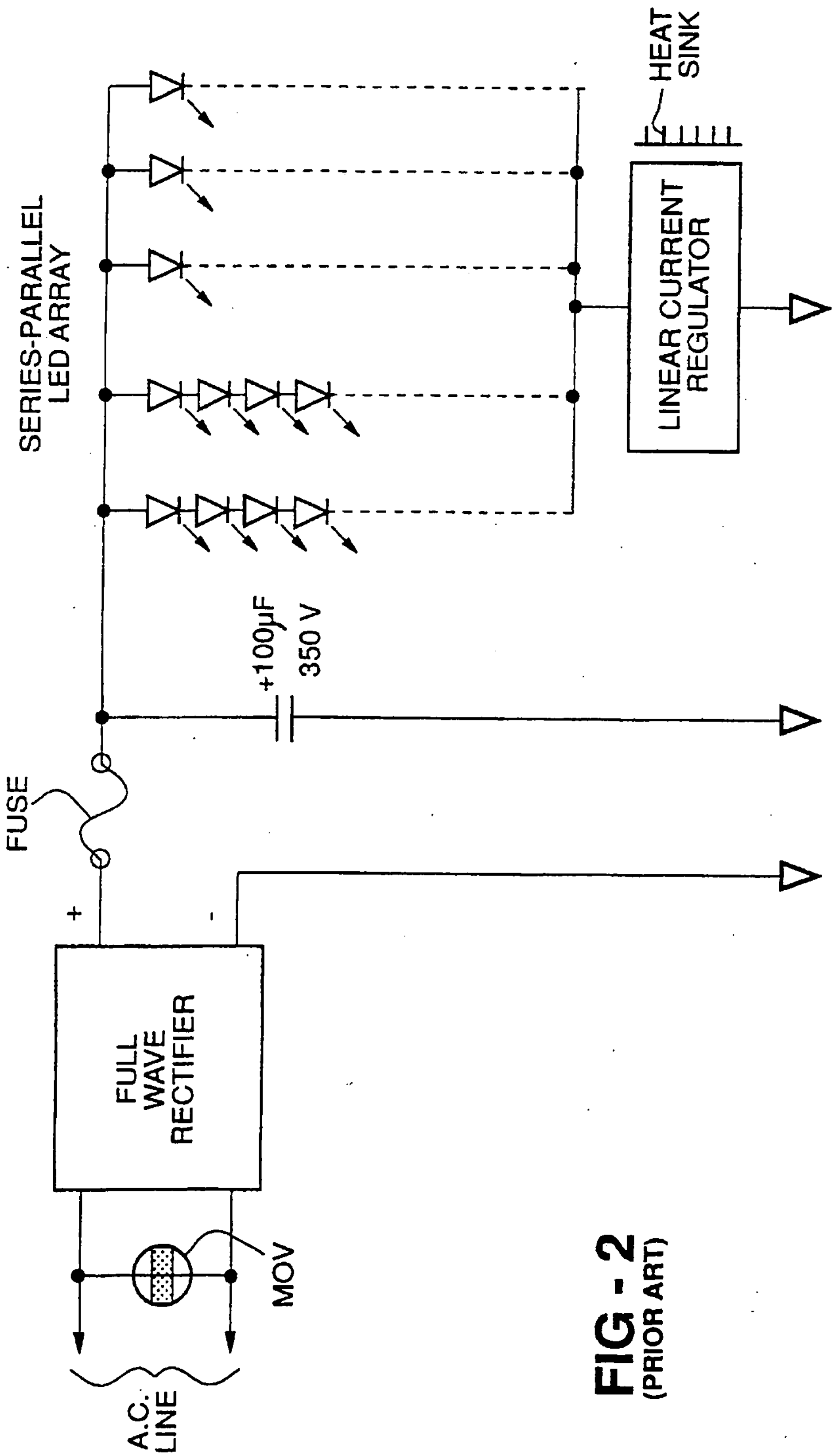


FIG - 2
(PRIOR ART)

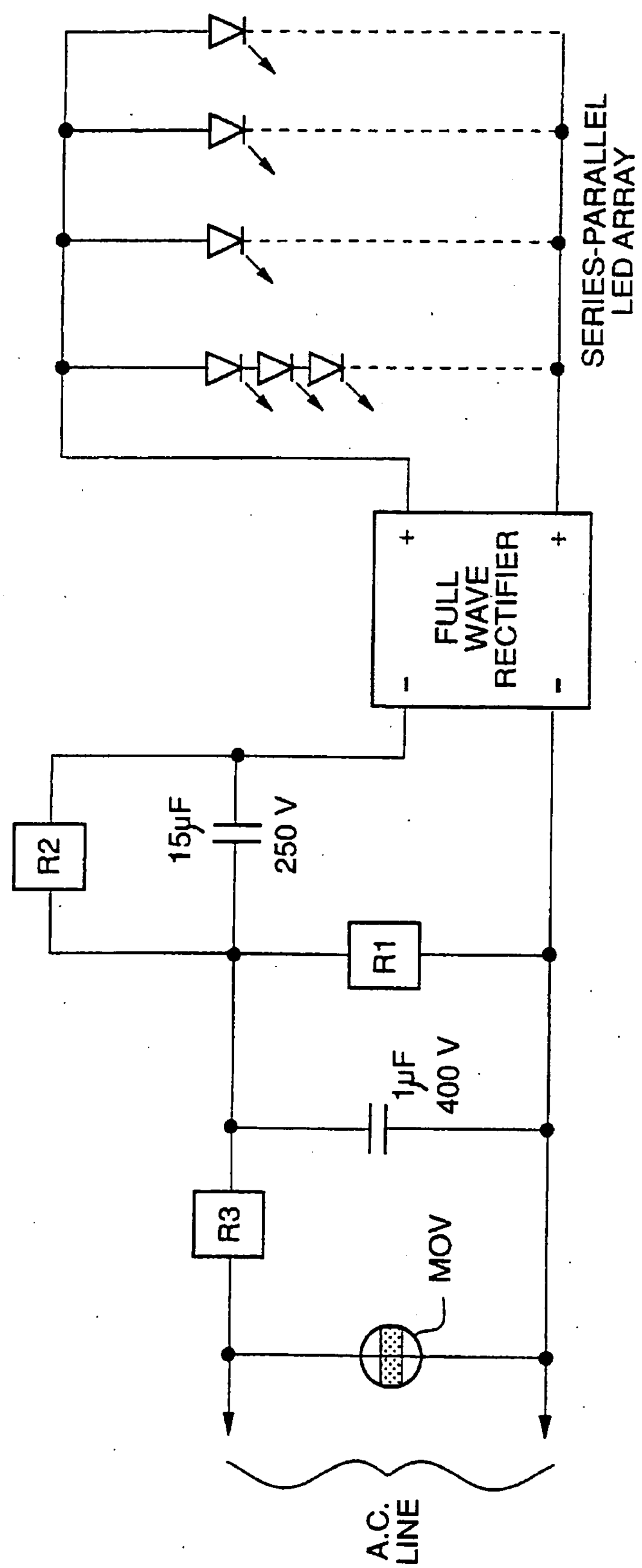


FIG - 3
(PRIOR ART)

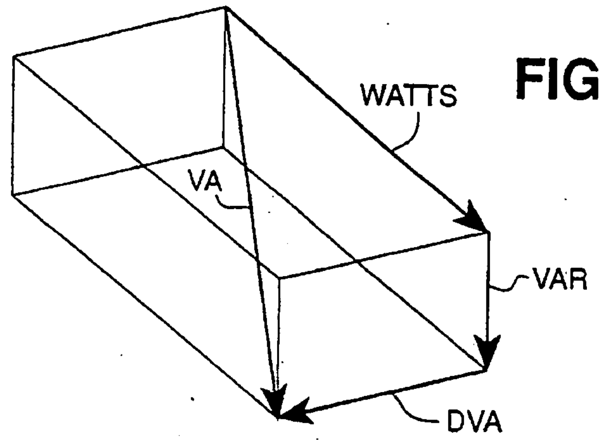


FIG - 4

FIG - 6a

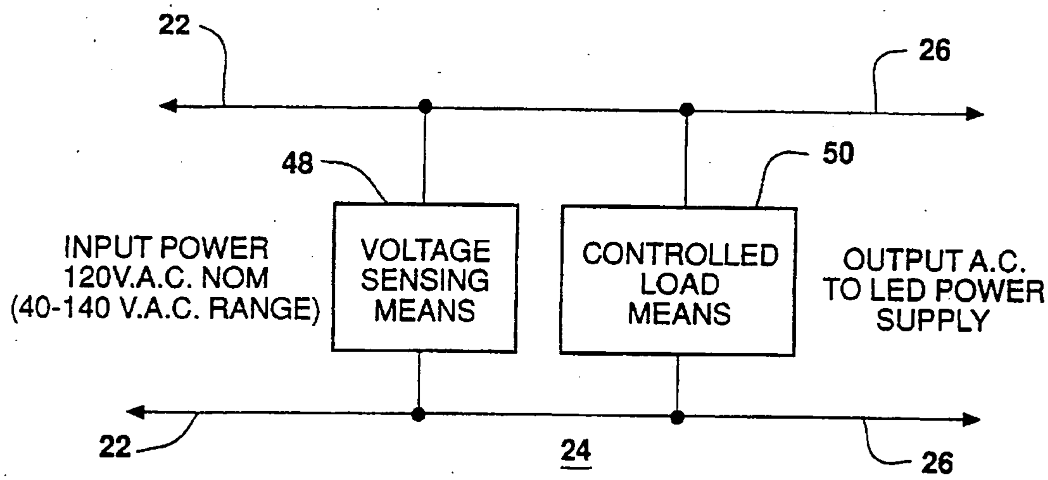
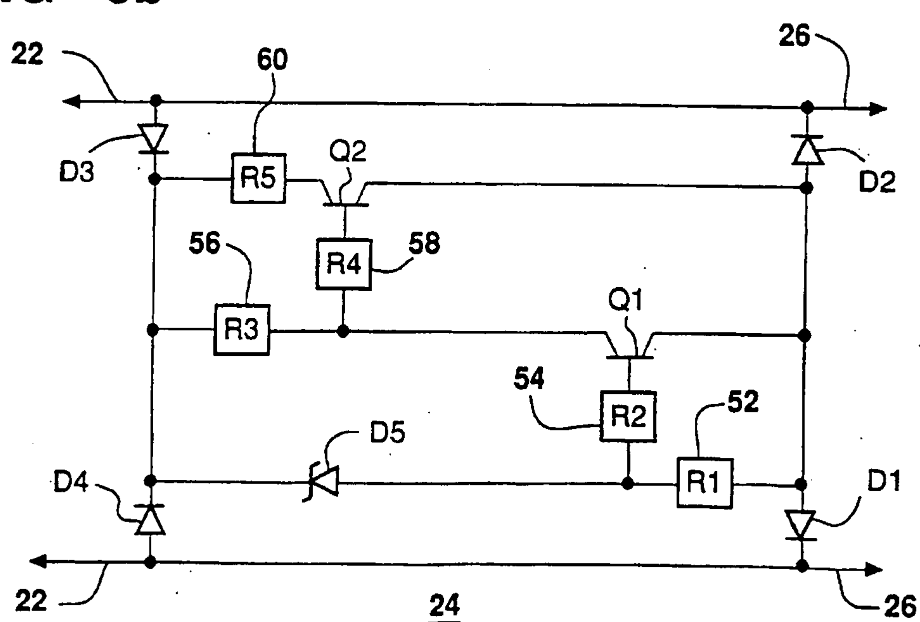


FIG - 6b



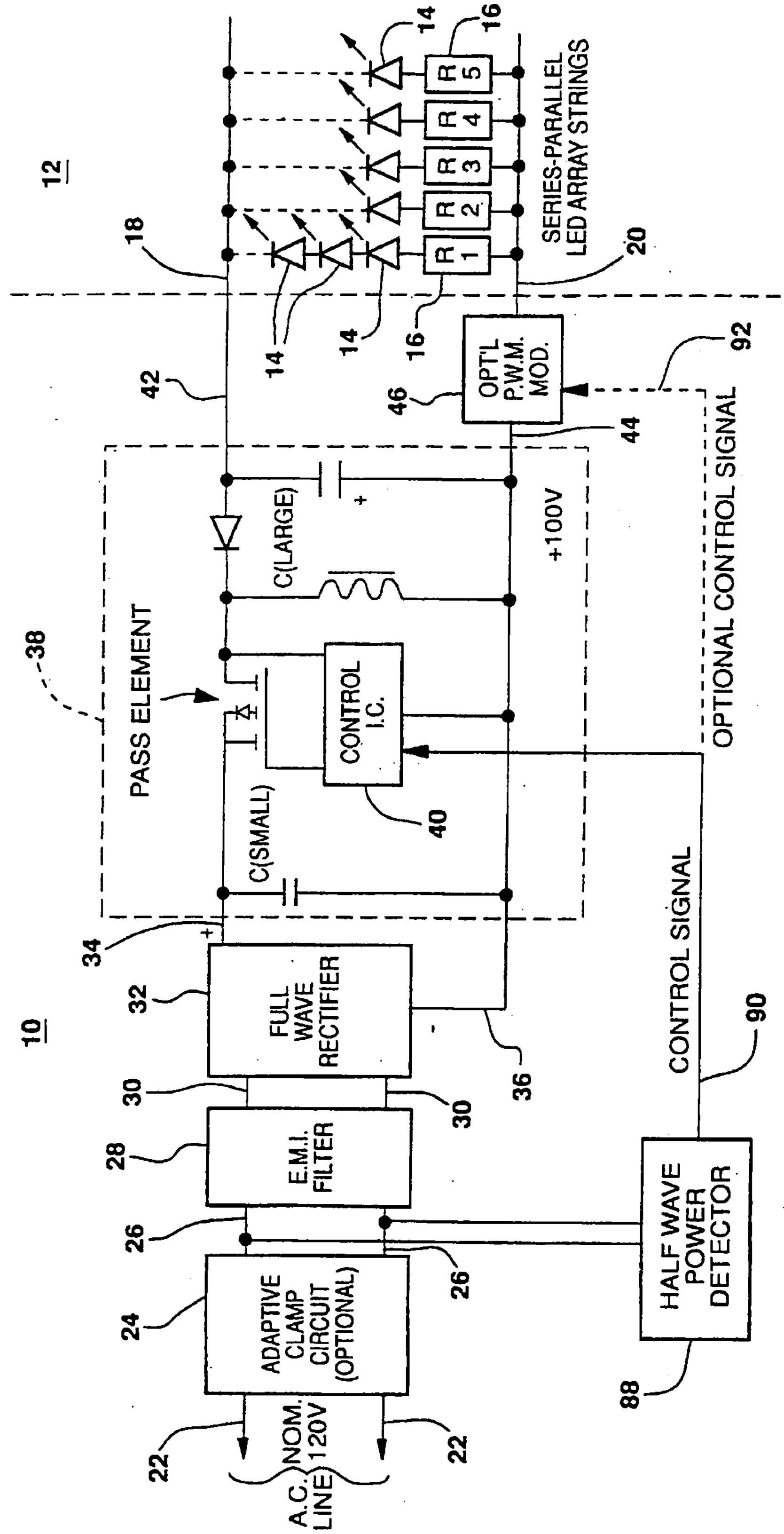

12
10
18
14
16
20
SERIES-PARALLEL LED ARRAY STRINGS
R 1
R 2
R 3
R 4
R 5
42
46
OPT'L P.W.M. MOD.
44
92
OPTIONAL CONTROL SIGNAL
C(LARGE)
+100V
38
PASS ELEMENT
CONTROL I.C.
40
C(SMALL)
34
32
FULL WAVE RECTIFIER
36
CONTROL SIGNAL
90
30
28
E.M.I. FILTER
26
24
ADAPTIVE CLAMP CIRCUIT (OPTIONAL)
HALF WAVE POWER DETECTOR
88
22
NOM. 120V
A.C. LINE

FIG - 5

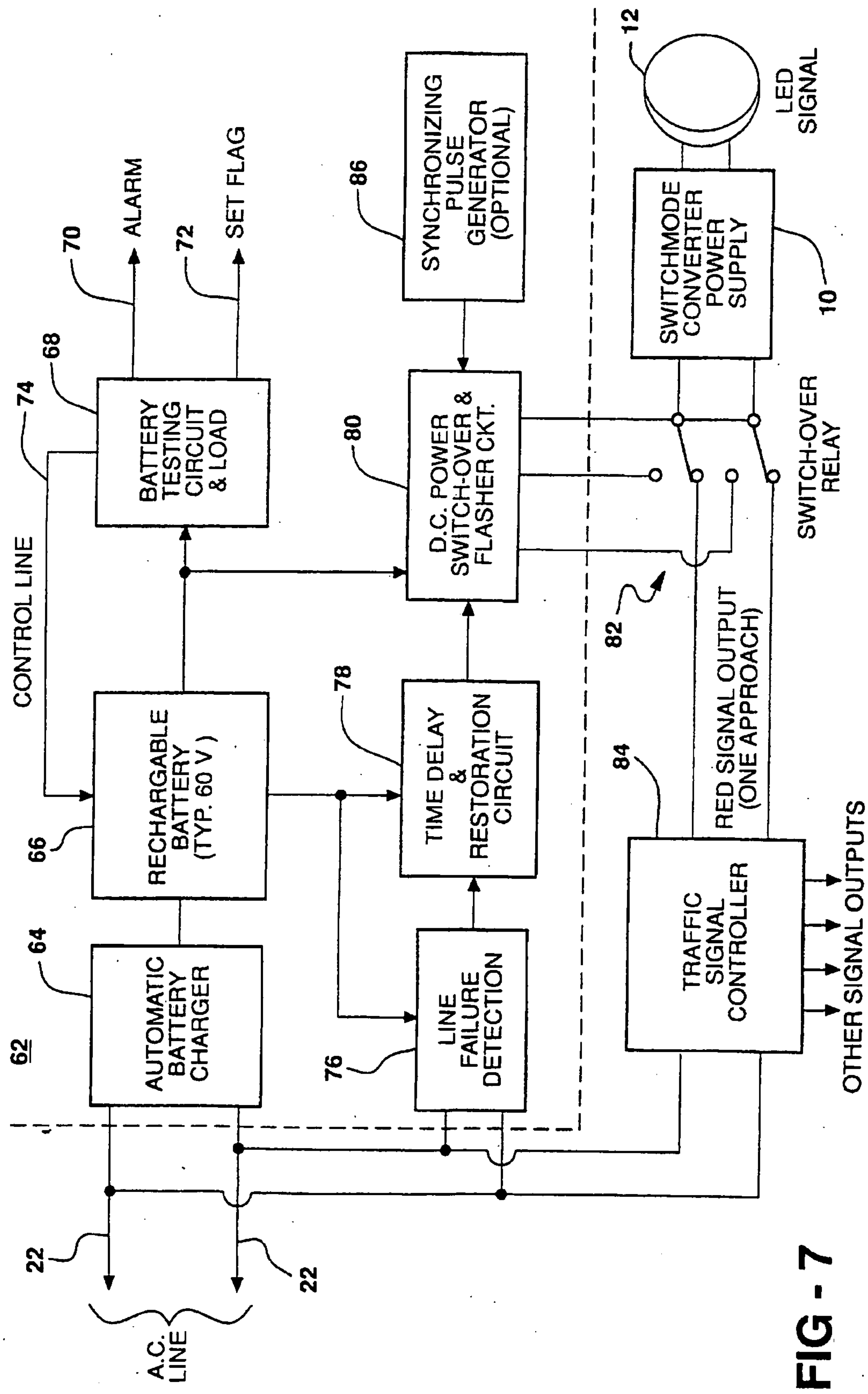

62
AUTOMATIC BATTERY CHARGER
64
RECHARGABLE BATTERY (TYP. 60 V)
66
CONTROL LINE
74
BATTERY TESTING CIRCUIT & LOAD
68
70
ALARM
72
SET FLAG
LINE FAILURE DETECTION
76
TIME DELAY & RESTORATION CIRCUIT
78
D.C. POWER SWITCH-OVER & FLASHER CKT.
80
SYNCHRONIZING PULSE GENERATOR (OPTIONAL)
86
82
84
TRAFFIC SIGNAL CONTROLLER
OTHER SIGNAL OUTPUTS
RED SIGNAL OUTPUT (ONE APPROACH)
SWITCH-OVER RELAY
SWITCHMODE CONVERTER POWER SUPPLY
10
LED SIGNAL
12
22
22
A.C. LINE

FIG - 7

POWER SUPPLY FOR LIGHT EMITTING DIODE ARRAY

BACKGROUND OF THE INVENTION

The present invention relates generally to an apparatus for generating power to a light emitting diode array and, in particular, to a power supply for operating light emitting diode array traffic signals.

Light emitting diode (LED) arrays are becoming more common in many applications as they are used to replace less efficient incandescent lamps. Status annunciators, message boards, liquid crystal display back lights and traffic signals are common applications for LED arrays. In most of these uses, electrical power is obtained from a.c. mains (120 v.a.c., 60 Hz) and some form of power supply converts the alternating line voltage to d.c., or pulsing d.c., for powering the plurality of LEDs.

LEDs typically exhibit forward voltage drops on the order of 1.2 to 2.0 volts when driven at average currents of 20 to 25 ma. For purposes of efficiency, the LEDs are usually connected in series so that a higher power supply voltage can be used to light an array of LEDs.

In many applications where a relatively large number of LEDs are necessary to deliver substantial light output, several series strings of LEDs with a ballasting resistor in each string are normally connected in parallel. As shown in the FIG. 1., this traditional circuit arrangement provides some redundancy from single point LED failure, as any "open" LED will only extinguish its own series string leaving the other strings active. Since this relatively simple circuit does not provide any regulation, i.e. the light output varies with varying input voltage, it has been generally superseded by the regulated circuit shown in the FIG. 2. The regulated circuit employs a linear current regulator instead of individual ballasting resistors to maintain a given current through the LED strings. The highly dissipative nature of such linear regulators makes such use questionable in heat sensitive apparatus such as LED signals however. Heat generated by the regulator could exacerbate the deterioration of the thermally sensitive LEDs.

A non dissipative, unregulated power supply for LED signals is shown in FIG. 3, and uses a series capacitor as the current limiting element. Such highly reactive power supplies exhibit very poor power factors however, and may be disallowed by power utilities.

Several problems are associated with these prior art simple circuit topologies. The input current wave forms are generally badly distorted and the power factor is poor. Reasons for the poor power factor and high distortion relate to the discontinuous conduction of the diodes in the circuit feeding large capacitors. This phenomenon is well understood, and plagues many small off line power supplies. Until recently these concerns were essentially disregarded by the electrical power industry because the impact to the power grid was relatively small. Of course, as larger numbers of these low power appliances are connected to the power grid, the effect is no longer inconsequential. In fact, many utilities are placing limits on permissible power factor and distortion behavior of electrical devices connected to their lines.

LED traffic signals are being retrofitted in place of incandescent lamps primarily because of the energy savings common to LED signals. For example, an 8 inch diameter incandescent signal might consume 67 watts and its LED equivalent 14 watts, or a 12 inch diameter incandescent signal would consume 150 watts while its LED replacement

would consume only 28 watts. The dramatic energy savings translate into greatly reduced operating cost, which is an important criterion, as electrical power is becoming more expensive. Also, in many parts of the country, electrical generating capacity is at its limits, and new capacity cannot be added because of environmental concerns. This strong interest in LED signals as an important energy conservation resource is clouded however by the poor power factor performance of commercially available signals.

Power factor (p.f.) is well understood in the electrical engineering community as the ratio of real power to real power plus reactive power, or more conveniently, p.f.=cos θ where θ is the angle in electrical degrees of the current-voltage phase offset. That is, in many reactive loads powered by sinusoidal (alternating) current, the voltage and current may be out of phase.

The apparent power that has to be delivered to a given load in volt-amperes (VA) is, therefore equal to the true power consumption of the device in Watts divided by the power factor. For example, an appliance with an internal power consumption of 100 Watts that exhibited a power factor of 0.4, would require 100/0.4 or 250 VA of energy from the power line and utility generator. Taken separately, the many small electrical appliances that are widely used have only a moderate effect on generating capacity. However in aggregate, a large number of small devices can have a significant impact on the power grid.

By means of example, a medium size city (San Francisco) may have some 2000 signalized intersections with a total of 16,000 mixed 8 inch and 12 inch traffic signals. If the existing incandescent signals with an average power consumption of 100 watts are replaced with LED variants of 20 watt rating, a significant power saving should result. The 1600 kilowatt (kW) load imposed by the incandescent signals should be reduced to 320 kw by the LED retrofit devices. However, if the LED signals exhibit an actual power factor of 0.3, the resulting load to the power grid is 320 kW divided by 0.3 p.f. or 1067 kW. The energy savings is then only 533 kW, which is the net mount of power that the utility can convert to other uses. Clearly then, the need for power factors close to unity is apparent. Another factor that directly influences the amount of power (apparent VA) that needs to be delivered to a given load is the total harmonic distortion of the current waveform supplying the device. True power factor is adversely affected by current or voltage distortion, and the significance of this influence is only now being widely accepted. There is shown in the FIG. 4, a traditional power factor vector diagram (which is normally two dimensional) which has been expanded to a three dimensional form to indicate the influence of distortion on the apparent power vector. The total power required vector VA (apparent power) is determined by the combination of the working power vector WATTS, the volt-amperes reactive vector VAR (non-working power) and the distortion volt-amperes vector DVA (non-working power).

Harmonic distortion or deviation from true sinusoidal wave forms not only gives rise to further wasted energy, but increases the electromagnetic interference potential of the load. Radiated and conducted interference is a concern because of the interference potential with other services (radio communications for example).

Harmonic distortion is becoming more prevalent in power supplies as these devices are converted from inefficient linear operation to far more efficient switchmode operation. A wide variety of circuit topologies are used in modern switching power supplies such as thyristor and triac phase

control, or bipolar or field effect transistor switches. A consequence of these solid state approaches is increased harmonic distortion and poor power factor behavior. In order to mitigate these problems, several approaches to power factor and distortion control have been developed that operate with and use the efficiency of the switchmode power supply itself. That is, instead of correcting for power factor in a separate functional device (that is connected between the power supply and line), the power factor and distortion correcting function is part of the switchmode power supply. A number of manufacturers of integrated circuits (Linear Technology, Silicon General, Motorola and Unitrode for example) offer monolithic devices that perform the power factor and distortion control function. A review of this art is presented in *Power Supply Cookbook* by Marty Brown, 1994, Butterworth-Heinemann.

SUMMARY OF THE INVENTION

The present invention concerns an apparatus for supplying regulated voltage d.c. electrical power to an LED array. The apparatus includes a rectifier having an input and an output, the rectifier being responsive to a.c. power at the input for generating rectified d.c. power at the output, a power factor correction converter having an input connected to the rectifier output and an output, the power factor correction converter being responsive to the rectified d.c. power at the power factor correction converter input for generating regulated voltage, d.c. power at the power factor correction converter output, and an LED array having an input connected to the power factor correction converter output for receiving the d.c. power to illuminate the LED array. The power factor correction converter can be a power factor correcting and voltage regulating buck/boost switchmode converter.

A primary object of the present invention is to provide a power factor correcting, (boost, buck/boost or buck) switchmode converter to power a line operated LED signal.

Another object of the present invention is to use the inherent pulse modulating nature of a switchmode power supply to provide voltage regulation to an LED array.

The apparatus according to the present invention also includes an adaptive clamp circuit connected to the rectifier input for eliminating leakage current problems. The adaptive clamp circuit has an input adapted to be connected to a pair of a.c. power lines, a pair of clamp circuit output lines connected to the adaptive clamp circuit input, a voltage sensing means connected across the adaptive clamp circuit input, and a controlled load means connected across the clamp circuit output lines and to the voltage sensing means. The voltage sensing means is responsive to a magnitude of a.c. voltage at the adaptive clamp circuit input lower than a predetermined magnitude for turning on the controlled load means to connect a low impedance load in the controlled load means across the clamp circuit output lines and the voltage sensing means is responsive to a magnitude of the a.c. voltage at the adaptive clamp circuit input equal to or greater than the predetermined magnitude for turning off the controlled load means to disconnect the low impedance load from the clamp circuit output lines.

It is also an objective of the present invention to eliminate leakage current problems by providing an adaptive clamp circuit.

Another feature of the present invention is to provide an adaptive line loading means or clamp that switches itself in or out of the circuit as needed.

The apparatus according to the present invention further includes a battery backup system having an input for receiving a.c. power applied to the rectifier input and having an output at which d.c. power is generated, and a switch-over relay connected to the battery backup system output and to the rectifier input, the battery backup system being responsive to a failure of a.c. power at the battery backup system input for controlling the switch-over relay to connect the battery backup system output to the rectifier input to provide d.c. power to illuminate the LED array and being responsive to a.c. power at the battery backup system input for controlling the switch-over relay to disconnect the battery backup system output from the rectifier input.

Another object of the present invention is the use of a d.c. power supply (instead of the a.c. power line) as a power backup that is activated upon a.c. power line loss.

BRIEF DESCRIPTION OF THE DRAWINGS

The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in the light of the accompanying drawings in which:

FIG. 1 is a schematic diagram of a prior art unregulated power supply for LED signals;

FIG. 2 is a schematic diagram of a prior art linear current regulated power supply for LED signals;

FIG. 3 is a schematic diagram of a prior art reactively ballasted power supply for LED signals;

FIG. 4 is a three dimensional vector diagram of the total power required to operate an LED array;

FIG. 5 is a schematic diagram of a regulated voltage, switchmode power supply for LED signals in accordance with the present invention;

FIG. 6*a* is a schematic block diagram of the adaptive clamp circuit shown in the FIG. 5;

FIG. 6*b* is a schematic diagram of the adaptive clamp circuit shown in the FIG. 6*a*; and

FIG. 7 is a schematic block diagram of a battery backup system for LED signals according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As noted above, the elementary power supplies that are currently used for powering LED array signals do not meet current standards for efficiency, reliability and performance. The unregulated, resistively ballasted power supply shown in the FIG. 1 does not isolate the LEDs from line voltage variations, and exhibits a poor power factor because of the rectifier and large capacitor. The commercially produced current regulated LED power supply, which is shown in the FIG. 2, does provide much better LED light intensity regulation with input voltage variation. However, the use of a linear, dissipative (heat producing) regulator presents problems. LEDs are thermally sensitive devices which degrade quickly at elevated temperatures. Since most power supplies for LED signals are part of, or are attached to the LED array, heat rise from the linear regulator can be deleterious. Furthermore, the traditional rectifier-capacitor circuit does not produce a satisfactory power factor.

The use of capacitors as non-dissipative current limiters in a.c. circuits is well established, and is shown in the FIG. 3 as another example of a commercially available LED array signal power supply. Current and voltage wave forms are essentially out of phase in this type of circuit, so that heat is not generated in the current limiting capacitor (15 μF).

However, the power factor and distortion performance of this type of circuit is very poor (P.F.≈0.3).

There is shown in the FIG. 5, a regulated voltage, switchmode power supply 10 according to the present invention connected to an LED array 12. The LED array 12 includes a plurality of strings of series connected LEDs 14 with a ballasting resistor 16 (R1, R2, R3, R4, R5, . . .) connected in each string. The strings are connected in parallel between a first input line 18 and a second input line 20 of the LED array 12.

The power supply 10 has a pair of power input lines 22 for connection to a source (not shown) of a.c. power such as main power lines at a nominal 120 volts a.c. An input of an adaptive clamp circuit 24 can be connected to the lines 22 as an option. A problem peculiar to signals that are switched by means of solid state relays is the leakage current that can flow through the load when the solid state switch or relay is "OFF". This phenomenon is common to triac and thyristor switches that are commonly employed in traffic signal controllers. While not apparent when incandescent signals are employed (because they are low impedance loads), the problems surface when relatively low power loads (such as LEDs) are connected to these same controllers. Typically, other safety devices used in traffic signal controllers such as conflict monitors must be "tricked" to reduce this leakage current. Commonly, a large capacitor is placed across the a.c. input leads to the LED load, in order to absorb the leakage current reactively. Of course, such provisions only aggravate the power factor problems.

An output of the adaptive clamp circuit 24 is connected by a pair of clamp circuit output lines 26 to an input of an electromagnetic interference (E.M.I.) filter 28. The E.M.I. filter 28 keeps conducted interference from feeding back into the power lines where it might cause problems to other circuitry on the line. An output of the filter 28 is connected by a pair of filter output lines 30 to an input of a rectifier means 32 which converts the incoming a.c. power to a pulsing d.c. power generated on a positive polarity rectifier output line 34 and a negative polarity rectifier output line 36. Although the rectifier means is shown as a full wave diode bridge rectifier, any type of rectifier can be used. The lines 34 and 36 are connected to an input of a power factor correction, buck/boost converter 38. The converter 38 includes a power factor correction (P.F.C.) integrated circuit (I.C.) controller 40, which is a commercial device available from many sources and functions by allowing current to charge a storage capacitor C (LARGE) only in phase with the rectified a.c. voltage thereby assuring a power factor close to unity. The control I.C. 40 also provides voltage regulation in the switchmode buck/boost converter by monitoring the output voltage and adjusting the high frequency on-off switching period of the pass element commensurately. Although a buck/boost converter is diagrammed, buck or boost topologies are also possible. Voltage output and current-mode control techniques are the primary differences in the various geometries, but these details are incidental to the functionality of the circuit.

A positive polarity output of the converter 38 is connected by a positive polarity converter output line 42 to the first input line 18 of the LED array 12. A negative polarity output of the converter 38 is connected by a negative polarity converter output line 44 to the second input line 20 of the LED array 12 through an optional pulse width modulated (P.W.M.) modulator 46.

The output voltage from the P.F.C. switch mode converter 38 is either fed directly to the LED array 12, or alternatively through the P.W.M. modulator 46. Such pulse modulation has been shown to be advantageous in certain LED signal applications. The functions of the switchmode P.F.C. converter 38 as the off line power supply are the same irrespective of the load. The obvious advantage of using a switching, voltage regulated power supply is efficiency. Line isolation, which is generally not provided by this transformerless design, is generally unnecessary for insulated LED signals, but a high frequency transformer could be incorporated. The intrinsic power factor correction provided by using the switchmode converter 38 in conjunction with the P.F.C. integrated circuit controller 40 is not only cost effective, but allows d.c. backup power to be used in case of line failure.

A primary aspect of the present invention is the use of a power factor correcting, (boost, buck/boost or buck) switchmode converter to power a line operated LED array signal 12. Another function of the present invention is to use the inherent pulse modulating nature of the switchmode power supply to provide voltage regulation to the LED array signal 12. Instead of using dissipative (heat producing) linear regulators for either voltage or current (to accommodate line voltage variations), the power factor and distortion controlling switchmode power supply 10 is used as an efficient voltage regulator. That is, the LED array 12, consisting of a large number of series-parallel connected LED devices 14, can be kept at essentially constant luminosity over a substantial range of input voltages. In actual practice, the output of such LED array signals has been kept within ±10% of nominal value over a power line variation of 85 volts to 140 volts (for a nominal 120 v.a.c. line).

It is also an objective of the present invention to eliminate leakage current problems by providing the adaptive clamp circuit 24 which is shown in more detail in the FIGS. 6*a* and 6*b*. The power input lines 22 are connected directly through the adaptive clamp circuit 24 to the clamp circuit output lines 26. The adaptive clamp circuit 24 monitors the input voltage feeding the LED array 12 on the input lines 22 with a voltage sensing means 48 connected across the lines 22 and loads the input lines resistively with a low impedance controlled load means 50, connected across the output lines 26, whenever the line voltage is below some critical amount (typically 40 volts a.c. r.m.s.). The adaptive clamp circuit 24 assumes that voltages lower than a certain value (typically 40 volts) are due to leakage currents through the solid state control relay or switch. The adaptive clamp circuit 24 loads the lines with a resistor to draw current, forcing the leakage voltage to a lower voltage (typically on the order of 10 volts a.c.) that will not cause problems for the conflict monitor or power factor correction (p.f.c.) circuit. Most traffic signals must be capable of being flashed (at least the red and yellow signals) from the traffic controller electronics. It has been found experimentally that residual leakage currents interfere with the ability to flash signals that are equipped with power factor correction circuits. The adaptive clamp circuit 24 prevents this problem by allowing the p.f.c. circuit to completely discharge between power line pulses which flash the signal at a nominal sixty flashes per minute. In summary, the adaptive clamp circuit 24 performs two functions by reducing the leakage voltage: 1) it provides a reactance free means to eliminate problems with conflict monitors (while preventing poor power factors); and 2) it allows the p.f.c. circuit to properly flash the LED array signal 12.

The adaptive clamp circuit 24 is shown in more detail in the FIG. 6*b* wherein a first pair of diodes D3 and D4 has anodes connected to the lines 22 and cathodes connected together. A second pair of diodes D1 and D2 has cathodes connected to the lines 26 and anodes connected together. A

first resistor (R1) 52 is connected between the junction of the second pair of diodes D1 and D2 and an anode of a Zener diode D5. The Zener diode D5 has a cathode connected to the junction of the first pair of diodes D3 and D4. A second resistor (R2) 54 is connected between the anode of the Zener diode D5 and a base of a first NPN transistor Q1. The transistor Q1 has an emitter connected to the junction of the second pair of diodes D1 and D2 and a collector connected through a third resistor (R3) 56 to the junction of the first pair of diodes D3 and D4. A fourth resistor (R4) 58 is connected between the collector of the transistor Q1 and a base of a second NPN transistor Q2. The transistor Q2 has an emitter connected to the junction of the second pair of diodes D1 and D2 and a collector connected through a fifth resistor (R5) 60 to the junction of the first pair of diodes D3 and D4.

The optional adaptive clamping circuit 24 is advantageously placed across the input terminals of the p.f.c., switchmode power supply 10 as shown in the FIG. 5. As noted above, as a consequence of using solid state relays or switches in signal controllers, the power to the signals is not fully disconnected (even when the signal should be off). This leakage current often causes problems with safety devices such as electronic conflict monitors. Additionally, these leakage currents may present problems during flashing operation of LED signals, as the power supply circuits may not be fully discharged between flashes. Switchmode, p.f.c. power suppliers of the type proposed for the present invention are particularly sensitive to such leakage currents and will be inhibited from flashing LEDs at an acceptable rate (55 to 60 flashes per minute).

In current practice, these leakage currents are minimized by "short circuiting" them by means of a reactive, non dissipative element. The input capacitor (typically 1–2 μF), as shown in the FIG. 3 for example, performs this function. However this same capacitor is across the line when the LED array signal is energized, drawing reactive power and contributing to a poor power factor.

Another feature of the present invention is to provide for an adaptive line loading means or clamp that switches itself in or out of circuit as needed. As shown in the FIG. 6*b*, the adaptive clamp circuit 24 monitors the line voltage, and when only leakage currents are present that drop the line voltage to about 40 v.a.c., the circuit applies a resistive load 60 across the lines 22 by turning on the solid-state switch Q2. When the lines 22 are loaded by the fifth resistor 60, having a suitable value (typically 1 kOhm), the leakage voltage will drop to under 10 volts. At this depressed voltage, the p.f.c. switchmode converter is fully off, and can properly flash the LEDs 14 at the requisite rate.

This adaptive clamp 24 can of course be used with other types of power supplies where the addition of reactive elements could degrade the power factor. The clamping circuit 24 works by using the sensing transistor Q1 and the Zener diode D5 (the voltage sensing means 48 of the FIG. 6*a*) to determine if the line voltage is below a certain magnitude (typically 40 volts). The sensing transistor Q1 and the Zener diode D5 are the voltage sensing means 48 of the FIG. 6*a*. If the Zener diode D5 does not conduct, the transistor Q2 is turned on to place the load resistor 60 the power lines 22 causing the leakage voltage to drop below 10 volts. The transistor Q2 and the resistor 60 are the controlled load means 50 of the FIG. 6*a*. Whenever the traffic signal controller relay "closes", the line voltage appearing at the input to the adaptive clamping circuit 24 rises to nominally 120 volts and the sensing circuit (Q1 and D5) turn off the controlling transistor Q2, removing the resistor 60 from the circuit thereby preventing unnecessary dissipation of power. Since there are no reactances involved, this circuit does not influence the power factor reflected at the a.c. input lines 22.

Another aspect of the present invention is the use of a d.c. input (instead of the a.c. power line) as a power backup feature that is activated upon power line loss. Conventional practice employs battery driven a.c. inverters to generate the backup power upon line failure. Such inverters are expensive, inefficient and are failure prone. The use of battery power (d.c.) to directly energize the regulated switchmode power supply that powers the LED array signal is very cost effective and energy efficient. The wide input voltage range of most switchmode power supplies allows the batteries to be used optimally as they can be virtually fully discharged in the power backup cycle yielding very good use of battery capacity. Lower cost, smaller batteries are therefore useable.

As noted previously, the use of a direct line operated, non-transformer isolated converter to power the LED array signal allows d.c. power to be used (instead of a.c.) in case of line failure. Using batteries without having to rely on an inverter to perform the d.c. to a.c. conversion is novel, extremely reliable, and cost effective. The importance of battery backup for critical traffic signals is obvious, and the need for reliability is also apparent. As shown in the FIG. 7, a battery backup system 62 includes a temperature compensated, line powered automatic battery charger 64 having an input connected to the lines 22 and an output connected to an input of a rechargeable battery 66 to keep the battery fully charged at all times that a.c. power is available. Temperature compensation can be used to stop the charging process to extend the life of the battery, as it is well known that the optimal end point charging voltage for most secondary cells is a function of temperature.

Because of the critical safety nature of these devices, an automatic battery testing circuit and load 68 is built into the battery backup system 62. Deterioration of the battery 66, which is inevitable over time, is thereby monitored and degradation past a certain point is flagged or announced. The testing circuit 68 has an input connected to an output of the battery 66 for sensing battery voltage. An alarm signal line 70 is connected to an output of the circuit 68 for generating the alarm signal and a set flag signal line 72 is connected to another output of the circuit 68 for generating the set flag signal. A control line 74 is connected between an output of the circuit 68 and an input of the battery 66. Secondary batteries that are kept in float service for any length of time tend to degrade and loose capacity. This deterioration is far more apparent in high temperature environments, and can adversely affect the safety margins of the backup power supply. That is, instead of providing 8 to 10 hours of flashing red LED array signal backup service, a degraded battery might only last a few hours. Determining the actual condition or serviceability of a storage battery is difficult, because a measurement of terminal voltage does not necessarily indicate loss of capacity. It has been experimentally determined that a good measure of battery capacity can be made by loading the battery with a substantial current (typically 5–10 amperes) for several minutes and measuring the terminal voltage under load. Naturally the battery charger is inhibited during this test. This method is well recognized as a good diagnostic test as it depletes any "surface charge" on the electrodes and more accurately indicates remaining battery ampere-hours.

A voltage comparator circuit in the battery testing circuit and load 68 establishes an "accept" or "reject" level for the battery 66 as it is tested every 24 hours or so. In order to

accommodate partly discharged cells, two sequential, battery tests that result in a "reject" are registered in a latch which may trigger a visual or audible alarm signal on the line 70. Alternatively, a relay or contact closure (flag) may be set to generate a signal on the line 72 so that a data modem can relay the degraded battery information to a central service facility. Of course, such calls or alarm signals are triggered well before the battery is no longer serviceable so that safety is not comprised.

A line failure detection circuit 76 has an input connected to the power lines 22 and another input connected to an output of the battery 66 to receive operating power from the battery. The circuit 76 initiates the power switch-over process whenever a.c. input power is disconnected. An output of the line failure detection circuit 76 is connected to an input of a time delay and restoration circuit 78 which has another input connected to an output of the battery 66 to receive operating power from the battery. The time delay function ensures that short, transient line dropouts are disregarded. An output of the time delay and restoration circuit 78 is connected to an input of a d.c. power switch-over and flasher circuit 80 which has another input connected to an output of the battery 66 to receive operating power from the battery. Outputs of the circuit 80 are connected to a first set of input terminals of a switch-over relay 82. The relay has a second set of terminals connected to red signal outputs of a traffic controller 84 having an input connected to the power lines 22. Output terminals of the switch-over relay 82 are connected to the input of the switchmode converter power supply 10 which is connected to the red LED array signal 12. Normally, the switch-over relay 82 is in the position shown to connect a.c. power on the lines 22 through the traffic controller 84 to the power supply 10.

Generally, line loss in excess of 250 msec will cause the d.c. power switch-over relay 82 to switch the output terminals to disconnect the power supply 10 and the red LED array signal 10 from the traffic controller 84 (and the a.c. feed) and connect them to the d.c. battery 66 through the d.c. power switch-over and flasher circuit 80. Note that the d.c. supply is flashed or pulsed by the circuit 80 at a nominal rate of 60 pulses per minute (1 Hz) to place all the red LED array signals at an intersection in a flashing mode, effecting a four way stop. While an electromechanical switch-over relay 82 is shown for complete isolation of the existing traffic controller 84 and the battery backup system 62, solid state devices could be used.

Whenever the line power is restored, the time delay and restoration circuit 78 will wait some period (typically 10–15 seconds) before the LED array signal 12 is switched back to the a.c. power mode. This delay avoids the many transients that usually accompany a.c. line restoration after a power outage. Note that no inverter is employed in this system, as is common practice in existing commercial hardware. The inefficiency and poor reliability of d.c. to a.c. converters is thereby avoided. Because the switchmode power supply 10 can accommodate wide variations in input voltage (both a.c. and d.c.) the storage battery 66 can be discharged virtually completely while maintaining essentially constant luminosity of the LED array signal 12.

Additionally, as shown in the FIG. 7, there are provisions for the introduction of narrow "marker pulses" superimposed on the d.c. supply for use as synchronizing pulses. An optional synchronizing pulse generator 86 has an output connected to an input of the d.c. power switch-over and flasher circuit 80 for generating such pulses. This optional feature permits a number of LED array signals that are pulse modulated to operate in sync in the absence of the 60 Hz a.c. line signal. These "marker pulses" are essentially short (200 μsec) power dropouts that do not affect the operation of the LED array signal 12, but are easily extracted at the signal to effect pulse synchronization of several pulsed LED array signals.

As noted above, the lack of input transformers or series capacitors before the full wave bridge, allows d.c. power to be applied at the input terminals of the power supply 10 in lieu of a.c. power. Since there are no reactive (a.c.) components in the input circuitry, proper operation of the switchmode converter is maintained, and output voltage regulation is still available. Obviously, the p.f.c. portion of the circuit 10 will be nonfunctional during operation on d.c. input power. As shown, the switchmode converter will provide an essentially constant output voltage (nom. 100 volts d.c.) to the LED array 12 over a range of a.c. input voltages from 85 volts r.m.s. to 140 volts r.m.s. and over a d.c. input voltage range of 38 volts d.c. to 65 volts d.c. The wide (input voltage) operating range allows rechargeable batteries to be used very efficiently, since their capacity can be fully utilized in the discharge cycle, as their terminal voltage drops.

As discussed above, LED signals are being used to replace incandescent lamps in many applications. Traffic signals are among the more common devices that are being upgraded for with LEDs because of the tremendous power savings and the dramatic improvement in service life. In most cases the incandescent lamps are merely replaced with an integral LED retrofit assembly that does not require any modification of the existing traffic signal housing or the drive and control circuitry associated with the signal. That is, users expect the LED retrofit lamps to operate normally without added modifications to the housing or traffic controller.

One aspect of this conversion to LED signals from incandescent lamps poses significant problems however. Many existing incandescent lamp traffic signals are dimmed at night to reduce glare and, of course, power consumption. LED signals can be dimmed by reducing the average current through the LED array. A problem arises however because existing traffic signal controllers dim incandescent signals by providing half-wave rectified a.c. to the devices. Normally the traffic lamps are powered by switched a.c. line power which has, in virtually all cases, a sinusoidal wave form. Simply rectifying this power allows the traffic signal controller to reduce the average voltage and current to the load in a loss free manner. This technique has been in common use for many years and has become the "defacto" standard dimming technique.

Most LED traffic signals do not work satisfactorily with half wave rectified a.c.; in fact, many simply do not light. Some LED lamp arrays which are equipped with regulated power supplies will illuminate satisfactorily when powered by half wave rectified a.c. current, but they do not dim. The regulated power supplies accept the half wave rectified a.c. line power and treat it merely as a low line voltage and correct for this phenomenon. The voltage impressed across the LED array is kept relatively constant in spite of such input voltage variations thereby keeping the LED luminous output essentially unchanged, i.e. undimmed.

Certain switchmode, regulating power supplies are able to power LED signals satisfactorily from even half wave rectified a.c. power supplies. A half wave detector circuit in the LED signal power supply can determine whether the traffic signal controller is sending a "dimming" command. Upon detection of this half wave signal, the switchmode

power supply can be programmed or adjusted to reduce its output voltage to the LED array. By adjusting either the pulse width or the frequency (at constant pulse width) of the switchmode power supply, the output voltage (and/or current) can be reduced in an efficient, nondissipative manner.

Alternatively, the half wave detector can be used to change the average current through the LED array by reducing the effective pulse width of a pulse width modulation controller that drives the LEDs. In either method, the average LED current and intensity are reduced in response to the detection of a half wave rectified input current. In this way, the LED signal is "transparent" to the user who may now utilize the LED device in the same manner as conventional incandescent signals.

As shown in the FIG. 5, a half wave power detector circuit **88** has inputs connected to the inputs of the full wave rectifier **32** at the clamp circuit output lines **26** to monitor the input a.c. power on the power input lines **22** to the power supply **10**. The detector **88** has an output connected to a control signal line **90** which is connected to an input of the control I.C. **40**. The detector **88** generates a control signal on the line **90** in response to the detection of a half wave dimming signal on the a.c. power lines **22**. The control signal is directed to the power supply regulator circuit **38**, where it causes the output voltage of the switchmode power supply **10** to be reduced in response to the dimming command. For current regulated power supplies, the average output current to the LED arrays can be reduced to effect dimming. In cases where the LED array is powered by a pulse width modulator, such as the modulator **46**, the connection of the line **90** to the control I.C. **40** is eliminated and the output of the detector **88** is connected by a control signal line **92** to an input of the modulator **46** such that the average current delivered to the LED array may be reduced by decreasing the pulse width of the modulator.

All such dimming methods have one key feature in common; the average current through the LED signal **12** is decreased in response to the detection of a half wave dimming signal impressed on the power supply input lines **22**. The detection of half wave power by the detector **88** causes the LED power supply **10** to either adjust the output pulse width at constant frequency or adjust the frequency at constant pulse width. The power supply **10** can be any type of power supply which converts a.c. power to d.c. power suitable for illuminating the LED array **12**.

The present invention is an apparatus **10** for supplying regulated voltage d.c. electrical power to an LED array including a rectifier means **32** having an input and an output, the rectifier means **32** being responsive to a.c. power at the input for generating rectified d.c. power at the output, a power factor correction converter means **38** having an input connected to the rectifier means **32** output and an output, the power factor correction converter means **38** being responsive to the rectified d.c. power at the power factor correction converter means input for generating regulated voltage, power factor corrected d.c. power at the power factor correction converter means output, and an LED array **12** having an input connected to the power factor correction converter means **38** output for receiving the power factor corrected d.c. power to illuminate the LED array **12**. The power factor correction converter means **38** can be a power factor correcting and voltage regulating buck/boost switchmode converter.

The apparatus **10** includes a pulse width modulated modulator means **46** connected to the power factor correction converter means **38** output and the LED array **12** input for modulating the power factor corrected d.c. power and an electromagnetic interference filter means **28** connected to the full wave rectifier means **32** input for preventing conducted interference from feeding back onto a.c. power lines **22** connected to the rectifier means **32** input. The apparatus **10** also includes an adaptive clamp circuit means **24** connected to the rectifier means **32** input for eliminating leakage current problems. The adaptive clamp circuit means **24** has an input adapted to be connected to a pair of a.c. power lines **22**, a pair of clamp circuit output lines **26** connected to the adaptive clamp circuit means **24** input, a voltage sensing means **48** connected across the adaptive clamp circuit means **24** input, and a controlled load means **50** connected across the clamp circuit output lines **26** and to the voltage sensing means **48**. The voltage sensing means **48** is responsive to a magnitude of a.c. voltage at the adaptive clamp circuit means **24** input lower than a predetermined magnitude for turning on the controlled load means **50** to connect a low impedance load **60** in the controlled load means **50** across the clamp circuit output lines **26** and the voltage sensing means **48** is responsive to a magnitude of the a.c. voltage at the adaptive clamp circuit means **24** input equal to or greater than the predetermined magnitude for turning off the controlled load means **50** to disconnect the low impedance load **60** from the clamp circuit output lines **26**.

The apparatus **10** further includes a battery backup means **62** having an input for receiving a.c. power applied to the rectifier means **32** input and having an output at which d.c. power is generated, and a switch-over means **82** connected to the battery backup means **62** output and to the rectifier means **32** input, the battery backup means **62** being responsive to a failure of a.c. power at the battery backup means **62** input for controlling the switch-over means **82** to connect the battery backup means **62** output to the rectifier means **32** input to provide d.c. power to illuminate the LED array **12** and being responsive to a.c. power at the battery backup means **62** input for controlling the switch-over means **82** to disconnect the battery backup means **62** output from the rectifier means **32** input. The switch-over means **82** can be an electromechanical relay. The battery backup means **62** includes a time delay and restoration means **78** responsive to application of a.c. power at the battery backup means **62** input for controlling the switch-over means **82** to disconnect the battery backup means **62** output from the rectifier means **32** input and connect the a.c. power to the rectifier means **32** input after a predetermined time delay. The battery backup means **62** also includes a d.c. power switch-over and flasher means **80** connected to the switch-over means **82** for pulsing the d.c. power at a predetermined rate to flash the LED array **12** and a synchronizing pulse generator means **86** connected to the d.c. power switch-over and flasher means **80** for imposing marker pulses on the d.c. power at a predetermined rate.

The apparatus **10** also includes a half wave power detector means **88** having an input connected to the input of the rectifier means **32** and an output connected to another input of the power factor correction converter means **38**, the half wave power detector means being responsive to a dimming signal at the rectifier means input for generating a control signal at said half wave power detector means output and the power factor correction converter means **38** being responsive to the control signal for decreasing the regulated d.c. power to dim the LED array **12**. If the apparatus **10** includes the pulse width modulated modulator means **46** connected to the power factor correction converter means **38** output and the LED array **12** input for modulating the regulated voltage

d.c. power, the half wave power detector means **88** has its output connected to an input of the pulse width modulated modulator means **46** and is responsive to a dimming signal at the rectifier means input for generating a control signal at the half wave power detector means output and the pulse width modulated modulator means **46** is responsive to the control signal for decreasing the regulated d.c. power to dim the LED array **12**.

In accordance with the provisions of the patent statutes, the present invention has been described in what is considered to represent its preferred embodiment. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.

What is claimed is:

1. An apparatus for supplying regulated voltage d.c. electrical power to an LED array comprising:
   - a rectifier means (**32**) having an input and an output, said rectifier means (**32**) being responsive to a.c. power at said input for generating rectified d.c. power at said output;
   - a power factor correction converter means (**38**) having an input connected to said output of said rectifier means (**32**) and an output, said power factor correction converter means (**38**) being responsive to said rectified d.c. power at said power factor correction converter means input for generating regulated voltage d.c. power at said power factor correction converter means output; and
   - an LED array (**12**) having an input connected to said output of said power factor correction converter means (**38**) for receiving said regulated voltage d.c. power to illuminate said LED array (**12**).

2. The apparatus according to claim **1** wherein said power factor correction converter means (**38**) is a power factor correcting and voltage regulating buck/boost switchmode converter.

3. The apparatus according to claim **1** including a pulse width modulated modulator means (**46**) connected to said output of said power factor correction converter means (**38**) and to said input of said LED array (**12**) for modulating said regulated voltage d.c. power.

4. The apparatus according to claim **1** including an electromagnetic interference filter means (**28**) connected to said input of said rectifier means (**32**) for preventing conducted interference from feeding back onto a.c. power lines (**22**) connected to said rectifier means input.

5. The apparatus according to claim **1** including an adaptive clamp circuit means (**24**) connected to said input of said rectifier means (**32**) for eliminating leakage current problems.

6. The apparatus according to claim **5** wherein said adaptive clamp circuit means (**24**) has an input adapted to be connected to a pair of a.c. power lines (**22**), a pair of clamp circuit output lines (**26**) connected to said adaptive clamp circuit means input, a voltage sensing means (**48**) connected across said input of said adaptive clamp circuit means (**24**), and a controlled load means (**50**) connected across said clamp circuit output lines (**26**) and to said voltage sensing means (**48**), said voltage sensing means (**48**) being responsive to a magnitude of a.c. voltage at said adaptive clamp circuit means input lower than a predetermined magnitude for turning on said controlled load means (**50**) to connect a low impedance load (**60**) in said controlled load means (**50**) across said clamp circuit output lines (**26**) and said voltage sensing means (**48**) being responsive to a magnitude of the a.c. voltage at said adaptive clamp circuit means input equal to or greater than said predetermined magnitude for turning off said controlled load means (**50**) to disconnect said low impedance load (**60**) from said clamp circuit output lines (**26**).

7. The apparatus according to claim **1** including a battery backup means (**62**) having an input for receiving a.c. power applied to said input of said rectifier means (**32**) and having an output at which d.c. power is generated, and a switch-over means (**82**) connected to said output of said battery backup means (**62**) and to said rectifier means input, said battery backup means (**62**) being responsive to a failure of a.c. power at said battery backup means input for controlling said switch-over means (**82**) to connect said output of said battery backup means (**62**) to said input of said rectifier means (**32**) to provide d.c. power to illuminate said LED array (**12**) and being responsive to a.c. power at said battery backup means input for controlling said switch-over means (**82**) to disconnect said battery backup means output from said rectifier means input.

8. The apparatus according to claim **7** wherein said switch-over means (**82**) is an electromechanical relay.

9. The apparatus according to claim **7** wherein said battery backup means (**62**) includes a time delay and restoration means (**78**) responsive to application of a.c. power at said input of said battery backup means (**62**) for controlling said switch-over means (**82**) to disconnect said output of said battery backup means (**62**) from said input of said full wave rectifier means (**32**) and connect the a.c. power to said full wave rectifier means input after a predetermined time delay.

10. The apparatus according to claim **7** wherein said battery backup means (**62**) includes a d.c. power switch-over and flasher means (**80**) connected to said switch-over means (**82**) for pulsing said d.c. power at a predetermined rate to flash said LED array (**12**).

11. The apparatus according to claim **7** wherein said battery backup means (**62**) includes a synchronizing pulse generator means (**86**) connected to said d.c. power switch-over and flasher means (**80**) for imposing marker pulses on said d.c. power at a predetermined rate.

12. The apparatus according to claim **1** including a half wave power detector means (**88**) having an input connected to said input of said rectifier means (**32**) and an output connected to another input of said power factor correction converter means (**38**), said half wave power detector means (**88**) being responsive to a dimming signal at said rectifier means input for generating a control signal at said half wave power detector means output and said power factor correction converter means (**38**) being responsive to said control signal for decreasing said regulated d.c. power to dim said LED array (**12**).

13. The apparatus according to claim **1** including a pulse width modulated modulator means (**46**) connected to said output of said power factor correction converter means (**38**) and to said input of said LED array (**12**) for modulating said regulated voltage d.c. power and a half wave power detector means (**88**) having an input connected to said input of said rectifier means (**32**) and an output connected to an input of said pulse width modulated modulator means (**46**), said half wave power detector means being responsive to a dimming signal at said rectifier means input for generating a control signal at said half wave power detector means output and said pulse width modulated modulator means (**46**) being responsive to said control signal for decreasing said regulated d.c. power to dim said LED array (**12**).

14. An apparatus for supplying regulated voltage d.c. electrical power to an LED array comprising:
   - a power supply means (**10**) having an input and an output, said power supply means (**10**) being responsive to a.c.

power at said input for generating regulated voltage d.c. power at said output to illuminate an LED array (12) connected to said power supply means output; and

a dimming detector means (88) having an input connected to said input of said power supply means (10) and an output connected to another input of said power supply means (10), said dimming detector means (88) being responsive to a dimming signal at said power supply means input for generating a control signal at said dimming detector means output and said power supply means (10) being responsive to said control signal for decreasing said regulated voltage d.c. power to dim the LED array (12).

15. The apparatus according to claim 14 wherein said dimming detector means (88) is a half wave power detector means, said dimming signal is half wave rectified a.c. power and said power supply means (10) includes a rectifier means (32) having an input connected to said power supply means input and an output and a power factor correction converter means (38) having an input connected to said rectifier means output and an output connected to said power supply output, said power factor correction converter means (38) including said another input of said power supply means (10), said power factor correction converter means (38) being responsive to said control signal for decreasing said regulated voltage d.c. power to dim the LED array (12).

16. The apparatus according to claim 14 wherein said dimming detector means (88) is a half wave power detector means, said dimming signal is half wave rectified a.c. power and including a pulse width modulated modulator means (46) connected to said output of said power supply means (10) for modulating said regulated voltage d.c. power, said pulse width modulated modulator means (46) including said another input of said power supply means (10), said pulse width modulated modulator means (46) being responsive to said control signal for decreasing said regulated voltage d.c. power to dim the LED array (12).

17. An apparatus for supplying regulated voltage d.c. electrical power to an LED array comprising:

a rectifier means (32) having an input and an output, said rectifier means (32) being responsive to a.c. power at said input for generating rectified d.c. power at said output;

a power factor correction converter means (38) having an input connected to said output of said rectifier means (32) and an output, said power factor correction converter means (38) being responsive to said rectified d.c. power at said power factor correction converter means input for generating regulated voltage d.c. power at said power factor correction converter means output;

a battery backup means (62) having an input for receiving a.c. power applied to said input of said rectifier means (32) and having an output at which d.c. power is generated; and

a switch-over means (82) connected to said output of said battery backup means (62) and to said input of said rectifier means (32), said battery backup means (62) being responsive to a failure of a.c. power at said battery backup means input for controlling said switch-over means (82) to connect said battery backup means output to said rectifier means input to provide d.c. power to said power factor correction converter means (38) to illuminate an LED array connected to said output of said power factor correction converter means (38) and being responsive to a.c. power at said battery backup means input for controlling said switch-over means (82) to disconnect said battery backup means output from said rectifier means input.

18. The apparatus according to claim 17 wherein said power factor correction converter means (38) is a power factor correcting and voltage regulating buck/boost switchmode converter.

19. The apparatus according to claim 17 including an adaptive clamp circuit means (24) connected to said input of said rectifier means (32) for eliminating leakage current problems, said adaptive clamp circuit means (24) having an input adapted to be connected to a pair of a.c. power lines (22), a pair of clamp circuit output lines (26) connected to said adaptive clamp circuit means input, a voltage sensing means (48) connected across said adaptive clamp circuit means input, and a controlled load means (50) connected across said clamp circuit output lines (26) and to said voltage sensing means (48), said voltage sensing means (48) being responsive to a magnitude of a.c. voltage at said adaptive clamp circuit means input lower than a predetermined magnitude for turning on said controlled load means (50) to connect a low impedance load (60) in said controlled load means (50) across said clamp circuit output lines (26) and said voltage sensing means (48) being responsive to a magnitude of the a.c. voltage at said adaptive clamp circuit means input equal to or greater than said predetermined magnitude for turning off said controlled load means (50) to disconnect said low impedance load (60) from said clamp circuit output lines (26).

20. The apparatus according to claim 17 wherein said battery backup means (62) includes a time delay and restoration means (78) responsive to application of a.c. power at said input of said battery backup means (62) for controlling said switch-over means (82) to disconnect said output of said battery backup means (62) from said input of said rectifier means (32) and connect the a.c. power to said rectifier means input after a predetermined time delay.

21. The apparatus according to claim 17 wherein said battery backup means (62) includes a d.c. power switch-over and flasher means (80) connected to said switch-over means (82) for pulsing said d.c. power at a predetermined rate to flash said LED array (12).

22. The apparatus according to claim 17 Wherein said battery backup means (62) includes a synchronizing pulse generator means (86) connected to said d.c. power switch-over and flasher means (80) for imposing marker pulses on said d.c. power at a predetermined rate.

23. An apparatus for supplying regulated voltage d.c. electrical power to an LED array comprising:

a rectifier means (32) having an input and an output, said rectifier means (32) being responsive to a.c. power at said input for generating rectified d.c. power at said output;

a power factor correcting and voltage regulating buck/boost switchmode converter (38) having an input connected to said output of said rectifier means (32) and an output, said switchmode converter (38) being responsive to said rectified d.c. power at said switchmode converter input for generating regulated voltage d.c. power at said switchmode converter output;

an LED array (12) having an input connected to said output of said switchmode converter (38) for receiving said regulated voltage d.c. power to illuminate said LED array (12);

a battery backup means (62) having an input for receiving a.c. power applied to said input of said rectifier means (32) and having an output at which d.c. power is generated; and

a switch-over means (82) connected to said output of said battery backup means (62) and to said input of said rectifier means (32), said battery backup means (62) being responsive to a failure of a.c. power at said battery backup means input for controlling said switch-over means (82) to connect said battery backup means output to said rectifier means input to provide d.c. power to said switchmode converter (38) to illuminate said LED array (12) and being responsive to a.c. power at said battery backup means input for controlling said switch-over means (82) to disconnect said battery backup means output from said rectifier means input.

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EXHIBIT B

US005463280A

United States Patent [19]

Johnson

[11] **Patent Number: 5,463,280**

[45] **Date of Patent: Oct. 31, 1995**

[54] **LIGHT EMITTING DIODE RETROFIT LAMP**

[75] Inventor: **James C. Johnson**, Conyers, Ga.

[73] Assignee: **National Service Industries, Inc.**, Atlanta, Ga.

[21] Appl. No.: **206,594**

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[51] **Int. Cl.**[6] **H05B 37/02**

[52] **U.S. Cl.** **315/187**; 362/800; 315/294; 315/324; 315/291

[58] **Field of Search** .... 362/800, 249, 362/252, 227, 234; 315/250, 324, 185 R, 185 S, 192, 188, 187, 193, 307, 291, 209 R, 224, 294, 310; 379/396

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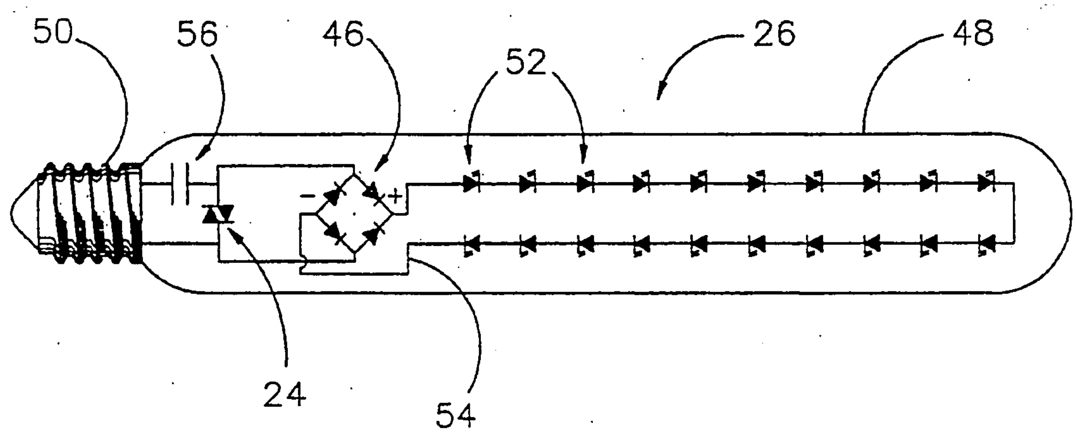
[57] **ABSTRACT**

A retrofittable lamp using light emitting diodes as the illumination source, the lamp is fitted with any one of the common lamp bases and is intended as a retrofit for incandescent lamps having such bases in illuminated signs such as exit signs and the like. The invention contemplates the packaging of a number of light emitting diodes in a circuit usually having a current limiting device to allow LED operation at a desired current level. The light emitting diodes are placed within a standard glass or plastic bulb envelope in arrangements capable of providing even illumination from the lamp.

8 Claims, 4 Drawing Sheets



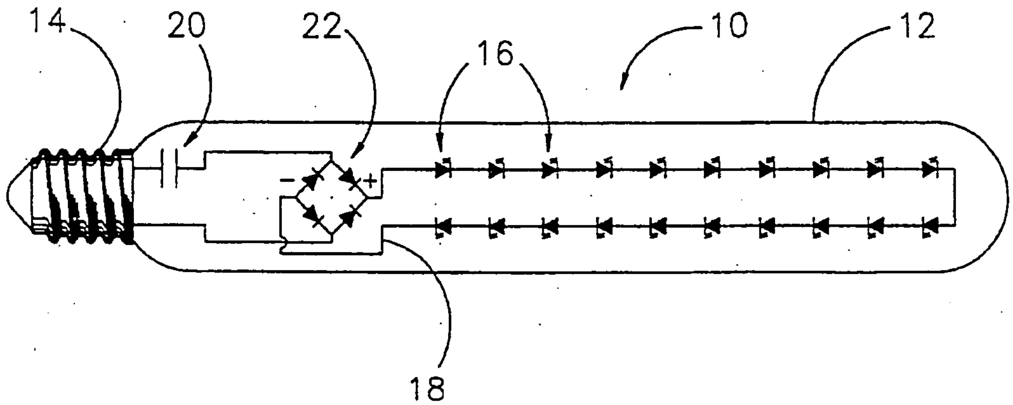


Fig. 1

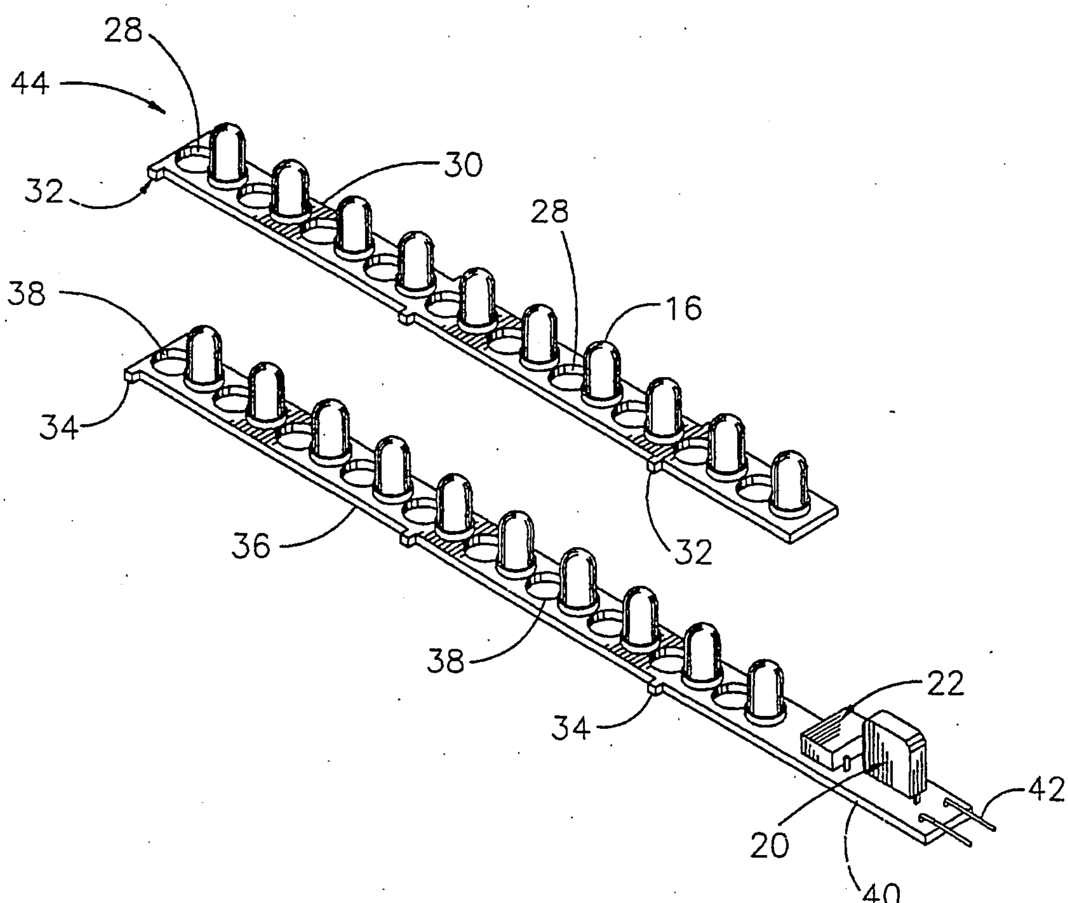


Fig. 2

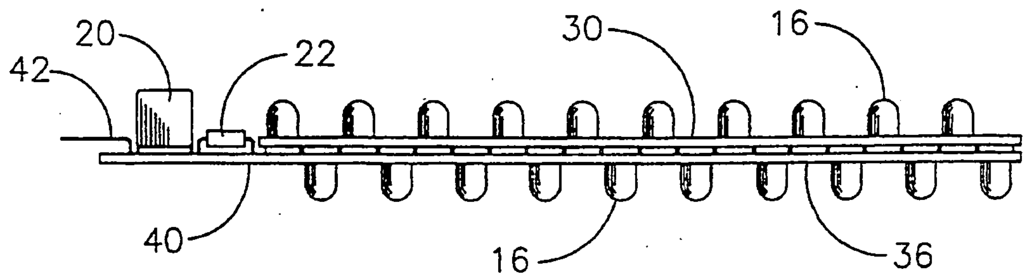


Fig. 3

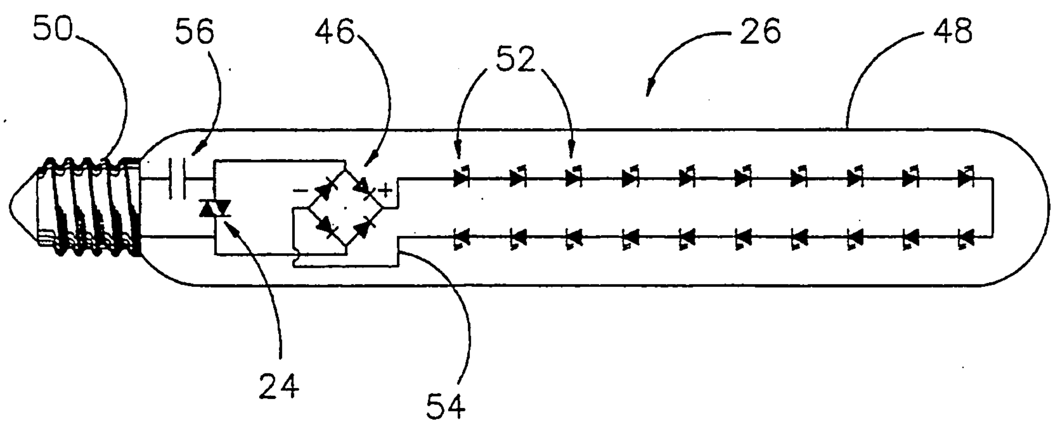


Fig. 4

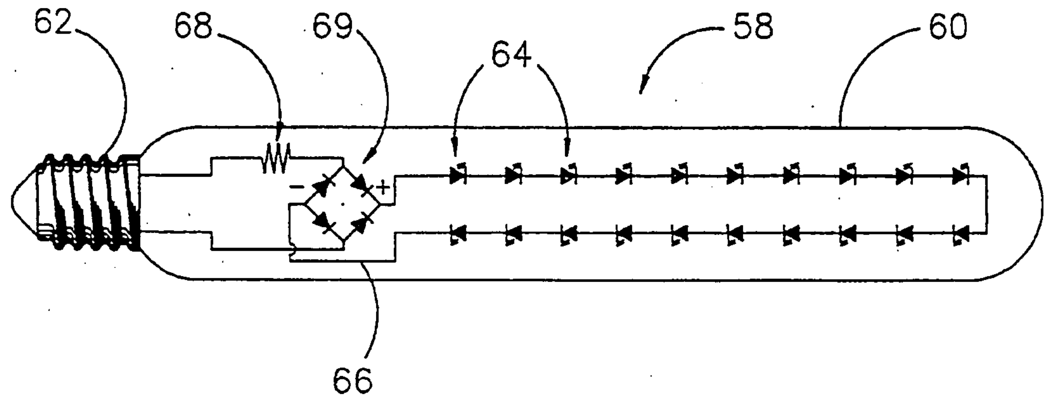


Fig. 5

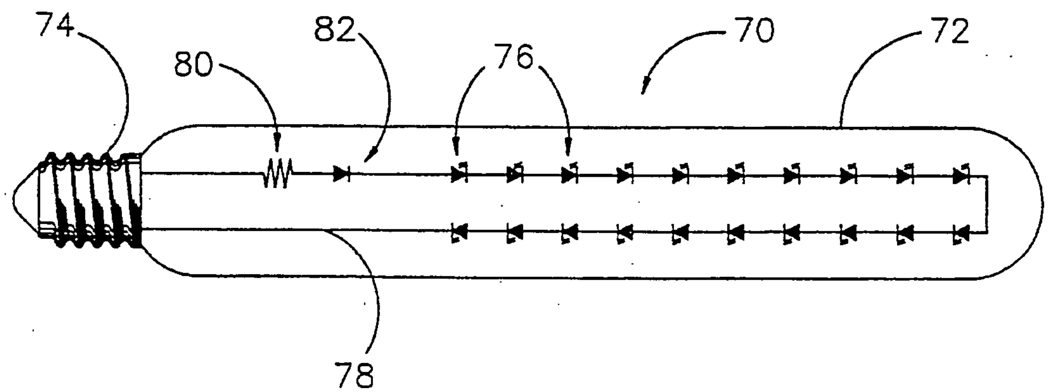


Fig. 6

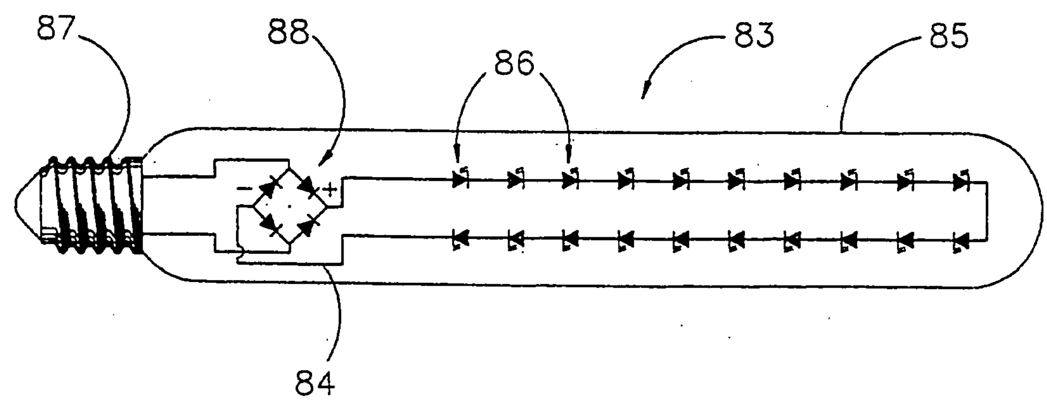


Fig. 7

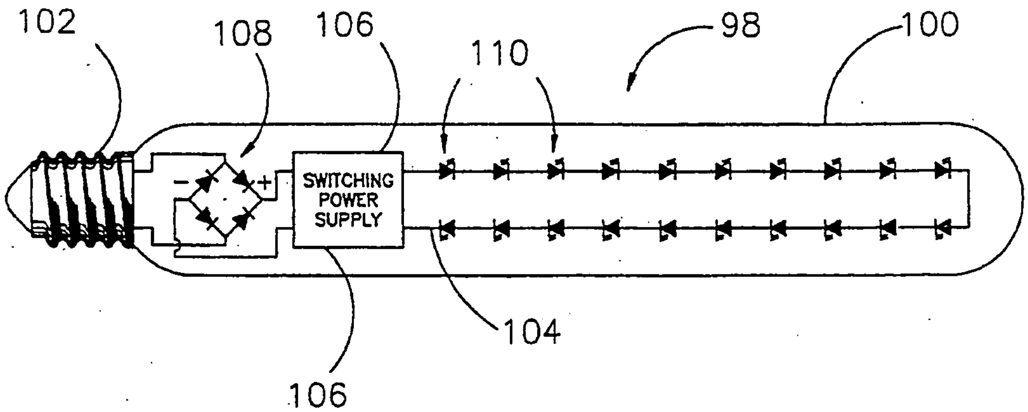


Fig. 8

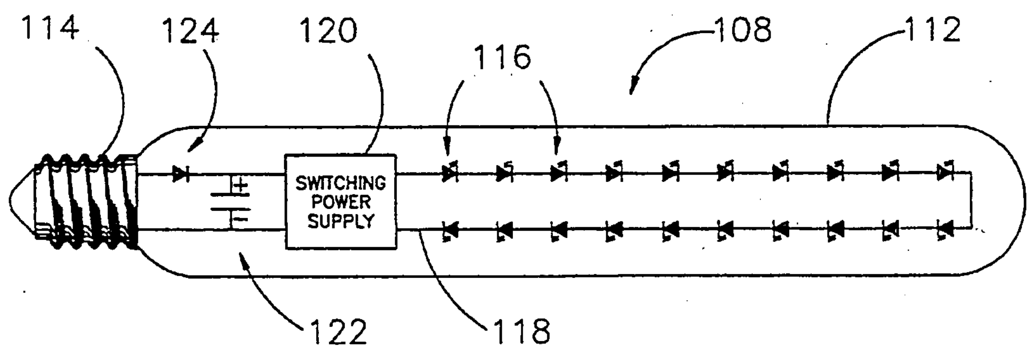


Fig. 9

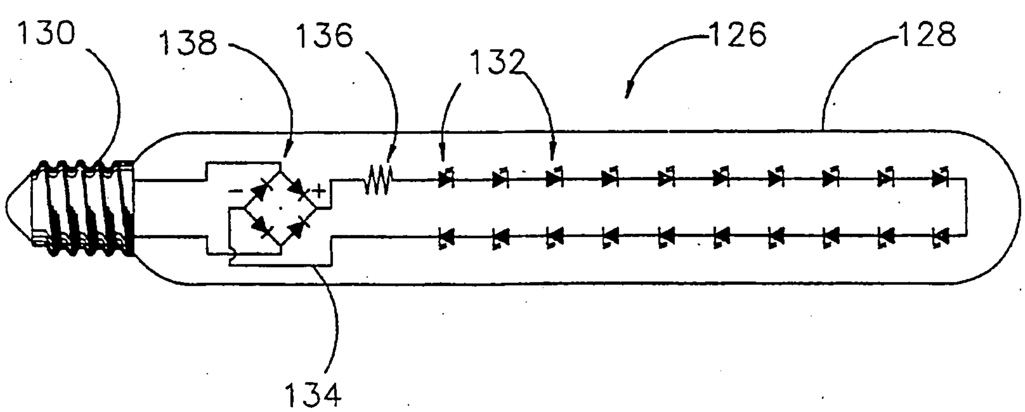


Fig. 10

LIGHT EMITTING DIODE RETROFIT LAMP

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to retrofittable lamps configured as standard incandescent lamps but with LED illumination soruces, the lamps of the invention being capable of substitution in illuminated signs such as exit signs and the like for previously used incandescent lamps.

2. Description of the Prior Art

It is estimated that approximately 40 million illuminated exit signs exist in operating capacities in this country at the present time. The great majority of this exit signage have as the illumination source one or more incandescent lamps. Millions of other illuminated signs also use incandescent lamps as the light source. While the incandescent lamps used in these illuminated signs have an exceptionally long life for incandescent lamps, a problem which exists with these lamps is the fact that the lamps burn out over time and must be replaced. Replacement of a burned out incandescent lamp in an illuminated sign with an essentially identical incandescent lamp is the common practice even though the necessity for replacement will again exist within a relatively short time even when the incandescent lamps are operated through a transformer at a reduced voltage in order to gain a longer lamp life. This basic problem has previously been recognized inter alia by Walton et al in U.S. Pat. Nos. 4,782,429 and 5,012,157, these patents describing lamps useful for replacement of incandescent lamps in exit signage and the like by the provision of low voltage, heated filament lamps which are intended to operate for a longer period of time than the incandescent lamps which have long been used in exit signage.

While illuminated signs have been proposed for a number of years with light emitting diodes as the illumination source, the use of light emitting diodes in original equipment exit signs has been expensive and, as importantly, the prior reliability of light emitting diodes has caused these illuminated signs to be less than practical. In recent years, light emitting diodes have improved to the point that such diodes have come into use as the original illumination source in certain categories of exit signage and the like. While the expense inherent in the use of light emitting diodes as the illumination source in an exit sign is still substantially greater than exit signs having incandescent or fluorescent illumination sources, the ability of the LED illumination source to provide extremely long life and energy efficiency has caused acceptance of LED-illuminated exit signs in the marketplace. Coincidental with the acceptance of LED-illuminated original equipment exit signage has been the provision of LED illumination sources in association with standard incandescent lamp bases to the end that the "solid state" or LED lamp so provided can be used in existing standard AC or DC lamp sockets. Ray, in U.S. Pat. No. 4,211,955, disposes light emitting diodes within a standard incandescent light bulb and lamp base. The solid state lamp thus provided by Ray can be used to replace any standard incandescent light bulb and inserted into existing standard AC or DC lamp sockets depending upon the standard base chosen. The circuitry of Ray includes an integrated circuit chip as a major portion of the operating circuit described in this patent. Uchida, in U.S. Pat. No. 4,727,289, disposes light emitting diodes on a printed circuitboard arranged inside a glass bulb having a base intended to be received into a standard socket. Power resistors used by Uchida are part of circuitry intended to provide a "high voltage" lamp but which also provides dissipative characteristics due to the wire-wound construction of the power resistors. In U.S. Pat. No. 4,939,427, Menard et al describe a lamp utilizing light emitting diodes as the illumination source, the lamp being insertable through a conventional base into a socket powered by an AC input. Other patents exist which utilize light emitting diodes as an illumination source whether with or without a covering envelope but with a base form intended to be received within a socket through which the LED illumination source is powered. Such patents include U.S. Pat. No. 4,290,095 to Schmidt, U.S. Pat. No. 4,630,183 to Fujita; U.S. Pat. No. 5,160,200 to Cheselske and U.S. Pat. No. 3,795,830 to Richardson. The disclosures of all of the patents mentioned hereinabove are incorporated hereinto by reference.

In view of the prior art described above, certain significant benefits are to be derived from a series connection of a significant number of light emitting diodes in arrangements proposed according to the present invention. The present circuit arrangements include attendant reduction of losses and stresses on circuit components. The invention thus provides LED illumination sources contained within a conventional glass or plastic bulb-like envelope of standard shape and dimensions and associated with common lamp bases such as intermediate, medium candelabra and double contact bayonet inter alia, such that the LED lamp of the invention can be retrofitted into existing exit signage which use incandescent lamps fitted with the corresponding lamp base.

SUMMARY OF THE INVENTION

The invention provides a retrofittable lamp having LED illumination sources packaged within a bulb envelope fitted with a common lamp base, the resulting lamp fitting into an incandescent socket and operable at line voltage in an illuminated sign such as an exit sign or the like. The illumination sources of the present retrofittable lamps primarily include light emitting diodes having a current limiting device in the circuitry. In at least certain embodiments of the invention, AC line voltage is converted to direct current. In the various embodiments of the invention, light emitting diodes are placed in series. In "high voltage" embodiments, a single resistor can function as a current limiting device with relatively larger numbers of light emitting diodes being used so that less voltage is applied across the resistor. In those embodiments of the invention wherein the current limiting device constitutes a capacitor, relatively few light emitting diodes can provide adequate illumination without excessive dissipative losses as heat.

The present LED lamps package all illumination sources and circuitry within the confines of a bulb envelope thereby eliminating the need for external circuitry or modifications to an installed exit sign. The several lamps of the invention simply screw or otherwise connect into the existing sockets within an installed exit sign. While the bulb envelope of the present LED lamps can conventionally be formed of glass, the interior of the bulb envelope would not require evacuation. Further, the bulb envelope could be formed of various plastic materials and could either be clear or frosted depending upon a desired affect.

Particular embodiments of the invention include the mounting of the light emitting diodes, connecting conductors and other circuit elements on boards whereby wire bonding techniques such as wave soldering allow connec-

tion of the light emitting diodes in series without significant failure rates. In a particular method of the invention, light emitting diodes and associated circuitry elements are wave soldered on a given side of two planar board elements which are then mounted "back-to-back" to allow the LED illumination sources to be directed in substantially all directions within the interior of the bulb envelope. Even illumination therefor results.

Accordingly, it is a primary object of the present invention to provide a retrofittable lamp utilizing light emitting diodes as the illumination source, the illumination source being fitted within a bulb envelope and base having the same size and shape of an incandescent lamp which the present LED lamp is intended to replace such as in an illuminated sign comprising an exit sign or the like.

It is another object of the invention to provide particularly efficient circuitry for retrofittable LED lamps capable of replacing previously used incandescent lamps in exit signage and the like.

A further object of the invention is to provide particular LED circuitry arrangements within the confines of a retrofittable lamp and socket and which are capable of providing even illumination.

Further objects and advantages of the invention will become more readily apparent in light of the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view of a lamp according to the invention with interior circuitry shown schematically;

FIG. 2 is a perspective view of a particular arrangement of light emitting diodes soldered to substrate elements by wave soldering techniques;

FIG. 3 is an assembly view of the structure shown in FIG. 2;

FIG. 4 is a side elevational view of a retrofittable lamp according to the invention schematically illustrating the circuitry of the lamp disposed interiorly thereof;

FIG. 5 is a side elevational view schematically illustrating a further embodiment of the invention;

FIG. 6 is a side elevational view schematically illustrating yet another embodiment of the invention;

FIG. 7 is a diagrammatical illustration of a circuit according to the invention; and,

FIGS. 8 through 10 are side elevational views of still further embodiments of the retrofittable lamp of the invention schematically illustrating the circuitry of the lamps.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings and particularly to FIG. 1, a preferred embodiment of the invention is illustrated as comprising a lamp **10** having a lamp tube **12** and a base **14**. While the lamps of the invention can be shaped and sized as desired to fit the exigencies of a particular use environment, the lamp **10** of FIG. **1** is particularly intended as a replacement lamp for an exit sign or similar illuminated sign which may have been originally fitted with an incandescent lamp. The lamp **10** of the invention is provided with a plurality of light emitting diodes **16** in series which fit within the lamp tube **12** and which form a part of a circuit **18** which includes the base **14** substantially in the manner that an incandescent filament in an incandescent lamp forms a part of a circuit which includes the base of the incandescent lamp. As such, the lamp **10** having the light emitting diodes **16** as its illumination source is capable of being used as a replacement lamp for a conventional incandescent lamp in an exit sign or illuminated sign. In the lamp **10**, the interior of the lamp need not be evacuated since it is not necessary to operate the light emitting diodes **16** in a vacuum. Accordingly, the lamp tube **12** can be formed of glass or from other materials such as various "plastic" materials and the lamp tube **12** can be formed with one or more openings (not shown) as desired. The lamp tube **12** in the embodiment of FIG. **1** is shaped identically to the bulb conventionally known in the art as a T6½ bulb with the base **14** being that type of base known as an intermediate base. It is to be understood that common lamp bases known in the art as medium, candelabra, double contact bayonet, etc. can also be employed as a base such as the lamp base **14** depending upon the structure of the conventional lamp which the lamps of the present invention are intended to replace. While the lamp tube **12** could be formed in a different shape, it will be understood that the shaping and sizing of the lamp **10** to substantially identical dimensions as those of the lamp which is to be replaced facilitates use of the lamp **10** as a replacement. As can readily be seen, the lamp tube **12** functions as a protective cover which holds the light emitting diodes within a desired spatial envelope so that the diodes **16** remain in place in a use environment. All other elements of the circuit **18** are preferably disposed within the spatial volume defined by the lamp tube **12** for protection of the circuit elements and to prevent contact between any element of the circuit **18** and structure exterior to the lamp **10**. Further, the lamp tube **12** acts to keep dust and the like from contacting either the diodes **16** or any part of the circuit **18** which might result in degradation of performance.

The lamp **10** would typically have a dimension of 5.5 inches in length in order to fit most incandescent lamp replacement situations in exit signage. The lamp **10** would further operate at a designed voltage of 120 volts which is the same voltage at which the incandescent lamp being replaced would operate within that socket (not shown) into which the base **14** connects to the line voltage. Voltages other than usual 120 VA can be employed. The lamp **10** has a design wattage of one watt, would have an operating temperature between −25° C. and +85° C. and a storage temperature between −25° C. and +100° C. The light emitting diodes **16** would be formed of conventional AlGaAs material and would operate at a peak wave length of 650 to 670 nm. Accordingly, the light emitting diodes **16** would preferably produce red light. The luminous intensity of each of the light emitting diodes **16** would be approximately 100 mcd at a minimum. As will best be seen relative to the following description of FIGS. **2** and **3**, the light emitting diodes **16** are spaced as uniformly as possible within the interior of the lamp tube **12** in order to provide even illumination. While the lamp **10** can be provided with varying numbers of the light emitting diodes **16**, very adequate illumination is provided by approximately 20 of the light emitting diodes **16** within the lamp **10** as shown in FIG. **1**. It is possible to use fewer than twenty diodes **16** or even a greater number of the diodes **16** depending upon the illumination level required.

The preferred embodiment of the invention shown in FIG. **1** is seen to include a capacitor **20** in the circuit **18** with a diode bridge **22** being located between the capacitor **20** and the light emitting diodes **16**. The capacitor **20** functions to limit current within the circuit **18** to the degree that the light emitting diodes **16** operate individually at approximately

0.02 amps. The capacitor **20** in the lamp **10** is preferably a 0.47 microfarad 120 AC device. The diode bridge **22** functions to convert AC line voltage to DC and provides full wave operation of the lamp **10**. The circuit **18** is joined in essentially a conventional fashion to interior electrically conductive portions of the base **14** as is the case with a conventional incandescent lamp. It is preferred that the capacitor **20** and the diode bridge **22** are located as close to the base **14** as is reasonably possible.

The embodiment of FIG. **1** can be configured as is shown in FIG. **4** with a varistor **24** such as an MOV as shown. The use of the varistor **24** is optional but does provide a surge-limiting function in circuit **54** of FIG. **4**. While the embodiment of FIG. **4** is substantially identical to the embodiment of FIG. **1** with the exception of the addition of the varistor **24**, the common elements between the two figures are identified by different numerical indicia. Accordingly, lamp **26** of FIG. **4** comprises lamp tube **48** and base **50** with the circuit **54** comprising light emitting diodes **52**, a diode bridge **46** and a capacitor **56**. Surge limiting devices such as the varistor **24** of FIG. **4** can be used in the circuitry of the other lamps described herein. Surge limiting devices are considered to be optional, however, since light emitting diodes do not have "negative resistance" characteristics such as do electrical discharge lighting devices and since such diodes do have at least some "positive slope" when considering the volt-amp characteristics of a typical light emitting diode. Accordingly, little current flows in a light emitting diode below certain threshhold levels. In essence, LED voltage increases dramatically with high current pulses and thus lessens a concern for off-line surges. Therefore, voltage sensing surge suppression devices such as the varistor **24** can be used for the additional protection thereby afforded.

A particular arrangement of the light emitting diode **16** can be conveniently manufactured according to the invention as is shown in FIGS. **2** and **3** for use in the lamp **10** (or with lamp tubes and base structures of differing type). As is particularly seen in FIG. **2**, the light emitting diodes **16** are spaced from each other and separated by a plurality of apertures **28** formed in an elongated circuit board substrate **30**, all of the light emitting diodes **16** on the substrate **30** extending from one side thereof and being interconnected by soldered portions (not shown) of the circuit **18** on the opposite sides of the substrate **30** from which the diodes **16** extend. The substrate **30** is provided with web tabs **32** which are mated with corresponding tabs **34** on substrate **36** which also mounts a series of light emitting diodes **16** separated by apertures **38**. While the tabs **32** and **34** hold the substrates **30** and **36** in a web of similar substrates during subsequent soldering, the tabs **32** and **34** also act to facilitate mounting of the assembled unit of FIG. **3** within the lamp tube **12**. The substrate **36** is provided with an extended plate **40** formed integrally with the substrate **38** for mounting of the capacitor **20** and the diode bridge **22**. Electrical contacts **42** extend from the end of the substrate **36** on which the capacitor **20** and diode bridge **22** are mounted. The contacts **42** connect (not shown in FIG. **2**) with the base **14**. The light emitting diodes **16** and the circuit **18** in which said diodes are connected are soldered while the substrates **30** and **36** are separate as is shown in FIG. **2** such as by wave soldering techniques which need not be described herein due to the conventional nature of the wave solder techniques per se. After wave soldering of the portions of the circuit **18** on those sides of the substrates **30** and **36** opposite the light emitting diodes **16**, the substrates **30** and **36** are assembled together as is shown in FIG. **3** with the light emitting diodes **16** disposed on either of the substrates **30** and **36** extending through the apertures **28** or **38** on the other of said substrates. In other words, the substrates **30** and **36** are mounted essentially "front-to-front" with the light emitting diodes on either substrate extending outwardly from the rear surface of each substrate when said substrates are bonded together. In order to mate the two portions of the structure together, that end **44** of the substrate **30** is placed next to the diode bridge **22** with that aperture **28** disposed nearmost said end **44** receiving the diode **16** nearmost the diode bridge **22** on the substrate **36**. Electrical connections (not shown) extend between the substrates **30** and **36** when assembled as seen in FIG. **3** to cause the diodes **16** and those circuit elements interconnecting the diodes **16** on the substrate **30** and **36** to electrically join all of the diodes **16**. In this arrangement, the light emitting diodes **16** extend within the lamp tube **12** in two oppositely disposed directions and provide substantially even illumination from within the lamp **10**. The structure of FIG. **3** will readily be understood to be inserted into the interior of the lamp tube **12** with the contacts **42** electrically connected to the base **14**. Attachment of the lamp tube **12** to the base **14** provides a lamp **10** which is ready for connection into an appropriate socket as a replacement lamp in an exit sign or similar illuminated sign.

Referring now to FIG. **5**, an embodiment of the invention is seen to comprise lamp **58** having lamp tube **60** and base **62**. A plurality of light emitting diodes **64** form a circuit **66** with a resistor **68**. In the circuit **66**, approximately 18 to 20 of the light emitting diodes **64** are connected in series with the resistor **68** which is chosen to be a 2200 ohm resistor. A diode bridge **69** is disposed in the circuit **66** between the resistor **68** and the light emitting diodes **64**. Although twenty of the light emitting diodes **64** are shown in FIG. **5**, a greater number of the diodes **64** can be employed. In essence, employment of greater numbers of light emitting diodes **64** causes the voltage seen across the resistor **68** to be reduced.

Referring now to FIG. **6**, a unidirectional or half-wave embodiment of the invention is seen to comprise lamp **70** having lamp tube **72** and base **74**. In this embodiment, approximately 18 to 20 light emitting diodes **76** are provided in series in circuit **78** which includes a 2200 ohm resistor **80** with a 1N4005 diode **82** being disposed in the circuit **78** between the resistor **80** and the light emitting diode **76**. In the event an exit sign into which the lamp **70** is placed uses a 277 to 120 (or 90) volt transformer (not shown), the current imbalances could be of concern were it not for the fact that the lamp **70** utilizes only a small fraction of the power previously supplied for the incandescent lamp (not shown) which the lamp **70** replaces. In the embodiment of FIG. **6**, the resistor **80** does not "see" a reverse voltage due to the provision of the diode **82** in the circuit **78**.

Referring now to FIG. **7**, a circuit **84** within lamp **83** is seen to contain light emitting diodes **86**, the circuit **84** being capable of operating the diodes **86** without a series impedance. A diode bridge **88** is placed in the circuit **84** and allows the circuit **84** to function without a series impedance. It is possible to use "strings" of the diodes **86** arranged in parallel for the single "string" of the diodes **86** seen in FIG. **7**. Such strings would typically include, e.g., as many as sixty-four of the light emitting diodes **86** with many multiples of the strings being potentially employed for redundancy. The diodes of the diode bridge **88** provide reverse polarity protection by means of the voltage blocking function which said diodes provide. A lamp having the circuit **84** would be able to take full advantage of the compounded affects of both a positive resistive slope and a quasi-pulsed form of operation for operating directly off-line.

Referring now to FIG. **8**, a lamp **98** configured according

to yet another embodiment of the invention is seen to comprise a lamp tube **100** and a base **102**. Circuit **104** includes light emitting diodes **110** and a diode bridge **108** with a switching power supply **106** disposed between the bridge **108** and the diodes **110**. The switching power supply **106** can take the form of a power factor controller which would cause this embodiment of the invention to have a desirably high power factor. A power factor controller such as the D suffix (S0–8) device produced by Motorola and designated MC34261 is suitable in this circuitry.

Referring now to FIG. **9**, a lamp **108** configured according to a further embodiment of the invention is seen to comprise a lamp tube **112** and a base **114**, a circuit **118** being contained within the lamp tube **112** and including electrically conductive portions of the base **114** in the circuitry for connection to line voltage or to any other appropriate voltage source. The circuit **118** contains in series a plurality of light emitting diodes **116** with a switching power supply **120** being contained in the circuit between the light emitting diodes **116** and a diode **124**. A capacitor **122** is connected in parallel with the switching power supply **120**. The switching power supply **120** can take the form of a power factor controller such as that device manufactured by Motorola and described hereinabove. The switching power supply **120** of FIG. **9** functions as a voltage reducing and current limiting device. The diode **124** functions as a reverse voltage blocking device and the capacitor **122** functions as a storage and smoothing device.

Referring now to FIG. **10**, a lamp **126** is seen to comprise a lamp tube **128** and a base **130** with circuit **134** being substantially contained within the lamp tube **128**. The circuit **134** includes a plurality of light emitting diodes **132** and a diode bridge **138** as shown. A resistor **136** is placed in series between the diode bridge **138** and the light emitting diodes **132**. The resistor **136** functions as a current limiting device while the diode bridge **138** acts to convert alternating current to direct current.

The various lamps of the invention can be provided in a kit form with reflective material intended to enhance reflectivity and illumination performance within the use environment of an exit sign. The reflective material (not shown) can be backed with adhesive to allow appropriate mounting within the exit sign. Red V glow and separate color panels can also be provided in such a kit.

A primary advantage of the lamps of the present invention is that the lamps are self-contained and do not require installation other than simple placement of any one of the lamps into a socket (not shown) intended to receive an appropriate base of an incandescent lamp which is to be replaced by one of the present lamps. Accordingly, one of the present lamps is simply screwed into an existing incandescent lamp socket without a requirement for circuity changes or any positioning or securing of a light emitting diode assembly within the sign which is to be illuminated. It is further to be understood that the preferred embodiment typically would use less than a single watt and, therefore, in a two-lamp exit sign, would require less than two watts of power as compared to the use of approximately 17 watts for "long-life" luminaires using low-voltage incandescent filaments. The circuitry of the present lamps is also simplified by the operation of the light emitting diodes in a series arrangement. Use of the present lamps will not usually require a transformer and rectifier circuit in an illuminated sign, thereby obviating the cost and complexity of conventional low-voltage direct current lamps. It is further to be understood that the present concept can be utilized in illuminated signs wherein fluorescent lamps have previously been employed.

Given the teachings of the invention as provided herein, it can be readily understood that the lamps illustrating the several embodiments of the invention can be configured other than as expressly shown in the drawings and described hereinabove. In particular, differing bulb envelopes can be substituted for the lamp tubes such as are shown herein, the shape, size and even the existence of a bulb envelope being dependent upon the use environment. Further, the base for the lamps configured according to the invention can vary depending upon the requirements of a particular use situation. Accordingly, the invention can be practiced other than as described hereinabove with the scope of the invention therefore being limited only by the recitations of the appended claims.

What is claimed is:

1. A lamp capable of operation on standard line voltages and particularly useful as a replacement lamp in an emergency exit sign and the like, comprising:

a plurality of light emitting diodes arranged in series and comprising a circuit locatable within the spatial confines of the lamp;

means disposed in the circuit for limiting current through the light emitting diodes, said means comprising a capacitor acting as the only effective limiting impedance in the circuit; and,

a diode bridge disposed in the circuit between the light emitting diodes and the capacitor.

2. The lamp of claim **1** wherein the circuit further comprises a varistor disposed in the circuit between the capacitor and the diode bridge to suppress current surges.

3. The lamp of claim **1** wherein the number of light emitting diodes in the circuit is approximately twenty.

4. A lamp capable of operation on standard line voltages and particularly useful as a replacement lamp in an emergency exit sign and the like, which exit sign is provided with at least one socket intended to receive a base of an exit sign lamp which is replaced by the present lamp, the present lamp having a base which can be received into the socket, comprising:

a plurality of light emitting diodes arranged in series and comprising a circuit locatable within the spatial confines of the lamp;

means disposed in the circuit for limiting current through the light emitting diodes, said means comprising a capacitor acting as the only effective limiting impedance in the circuit; and,

means for rectifying current disposed in the circuit between the light emitting diodes and the capacitor.

5. The lamp of claim **4** wherein the rectifying means comprise a diode bridge.

6. The lamp of claim **5** wherein the number of light emitting diodes in the circuit is approximately twenty.

7. A lamp capable of operation on standard line voltages and particularly useful as a replacement lamp in an emergency sign and the like, comprising:

a plurality of light emitting diodes arranged in series and comprising a circuit locatable within the spatial confines of the lamp;

a single circuit element arranged in the circuit for limiting current through the light emitting diodes, the single circuit element comprising the only effective limiting impedance in the circuit and comprising a capacitor; and,

a diode bridge disposed within the circuit between the

light emitting diodes and the single circuit element.

8. A lamp capable of operation on standard line voltages and particularly useful as a replacement lamp in an emergency sign and the like, comprising:

a plurality of light emitting diodes arranged in series and comprising a circuit locatable wtihin the spatial confines of the lamp;

a single circuit element arranged in the circuit for limiting current through the light emitting diodes, the single circuit element comprising the only effective limiting impedance in the circuit; and,

a diode bridge disposed within the circuit between the light emitting diodes and the single circuit element, the single circuit element comprising a capacitor.

* * * * *

EXHIBIT C

United States Patent [19]

Hildebrand

[11] **Patent Number: 5,075,601**

[45] **Date of Patent: Dec. 24, 1991**

[54] **POWER SUPPLY DYNAMIC LOAD FOR TRAFFIC AND PEDESTRIAN SIGNAL**

[76] Inventor: Cleve R. Hildebrand, 3000 E. Las Hermanas St., Rancho Dominguez, Calif. 90221

[21] Appl. No.: **514,143**

[22] Filed: **Apr. 25, 1990**

[51] **Int. Cl.**[5] **H05B 37/02**

[52] **U.S. Cl.** **315/291**; 315/224; 307/304; 307/140; 361/56

[58] **Field of Search** .... 315/291, 310, 224, DIG. 7; 307/135, 140, 157, 490, 264, 322; 361/56; 323/299, 303; 363/37, 89

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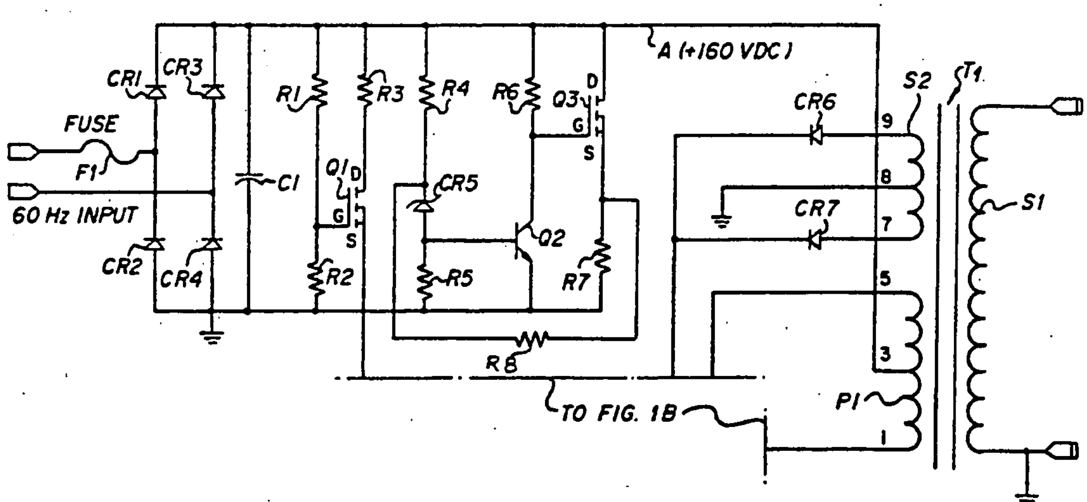
Primary Examiner—Eugene R. Laroche

Assistant Examiner—Son Dinh

[57] **ABSTRACT**

A dynamic load circuit constructed so that the current shunted thereby is high at low voltages and low at high voltages. The impedance of the dynamic load circuit is negative over a portion of its operating range so that current will decrease with increasing voltage over that range. The foregoing is accomplished by the provision of a two-stage inverting direct current amplifier with a low impedance load and a selected offset voltage.

2 Claims, 5 Drawing Sheets



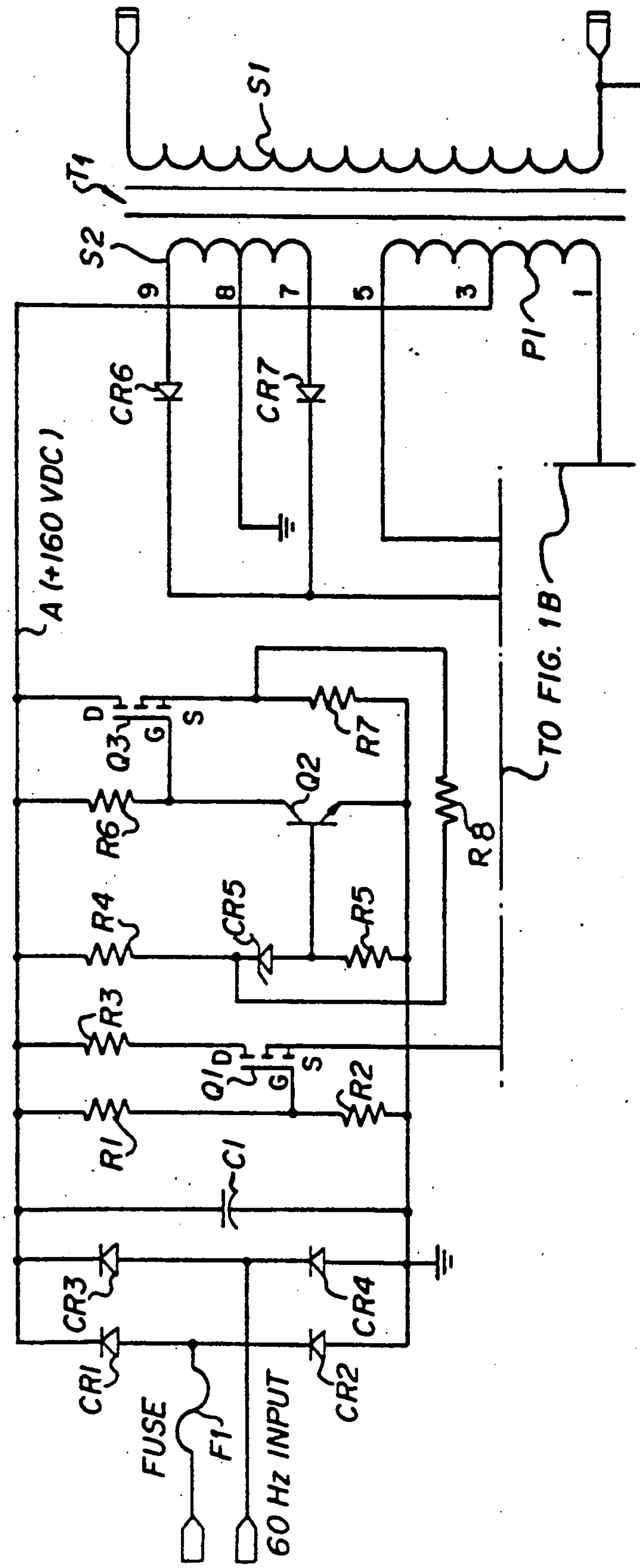

S1
T1
S2
9
8
7
5
3
1
P1
CR6
CR7
A (+160 VDC)
TO FIG. 1B
D
G
S
Q3
R7
Q2
R6
R8
R4
CR5
R5
R3
Q1
R2
R1
C1
CR3
CR4
CR1
CR2
FUSE
F1
60 Hz INPUT

FIG. 1A

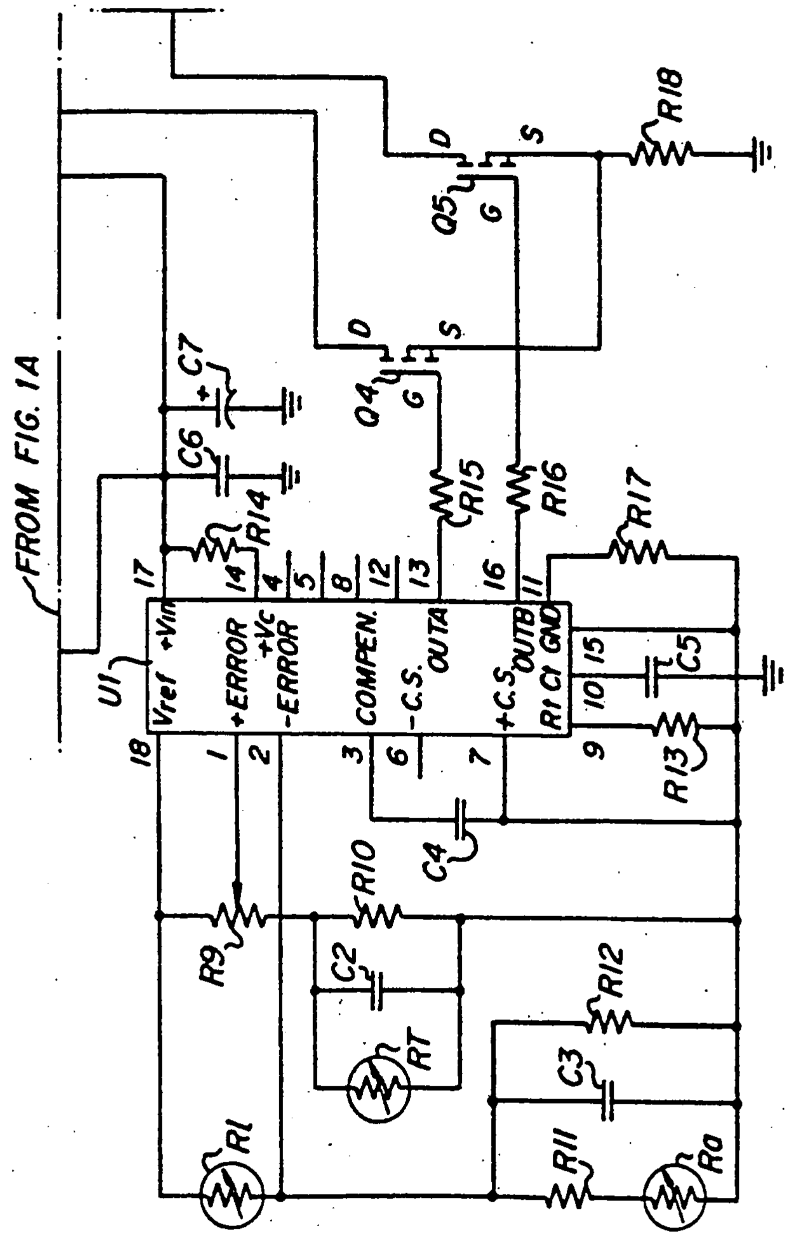

FROM FIG. 1A
U1
Vref
+Vin
+ERROR
+Vc
-ERROR
COMPEN.
-C.S.
OUTA
+C.S.
OUTB
R1 C1 GND
17
18
14
4
5
8
12
13
16
11
1
2
3
6
7
9
10
15
C7
C6
R14
R15
R16
R17
Q4
Q5
D
G
S
R18
C5
R13
C4
R9
R10
C2
RT
R12
C3
R11
R1
Ra

FIG. 1B

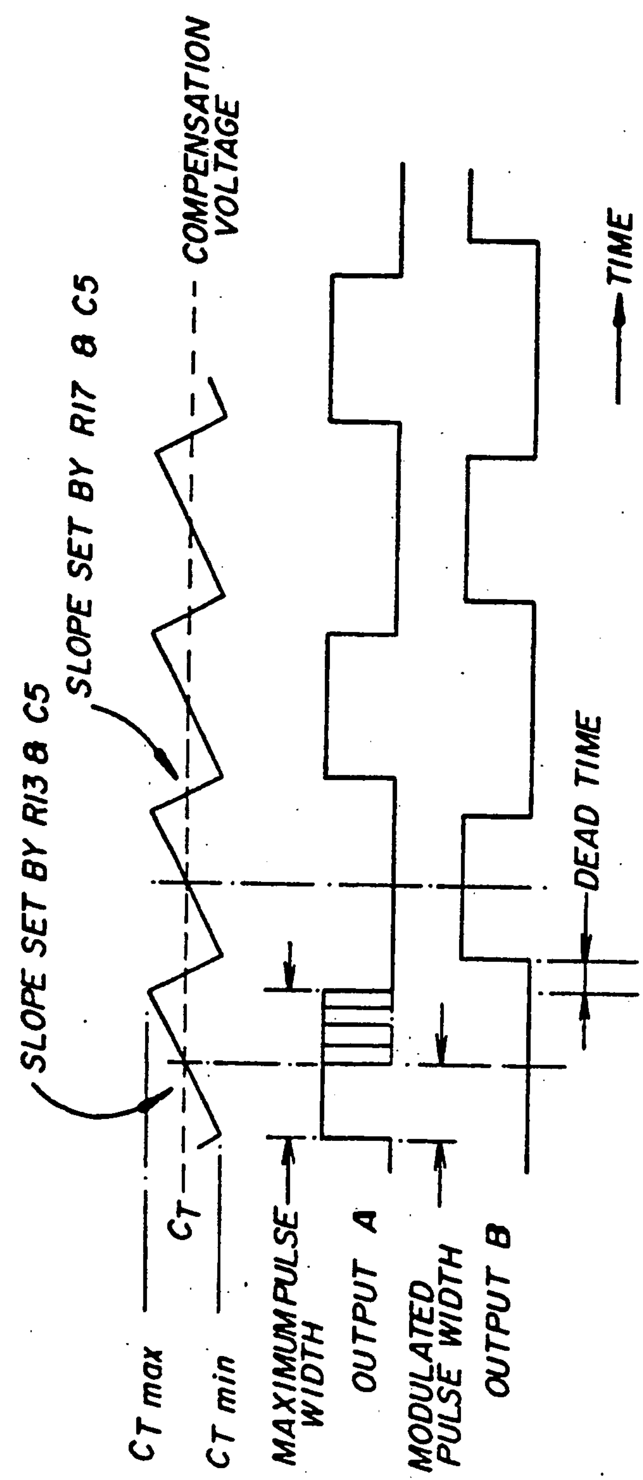

SLOPE SET BY RI3 & C5
SLOPE SET BY RI7 & C5
COMPENSATION VOLTAGE
C_T max
C_T
C_T min
MAXIMUM PULSE WIDTH
OUTPUT A
MODULATED PULSE WIDTH
OUTPUT B
DEAD TIME
TIME

FIG. 2

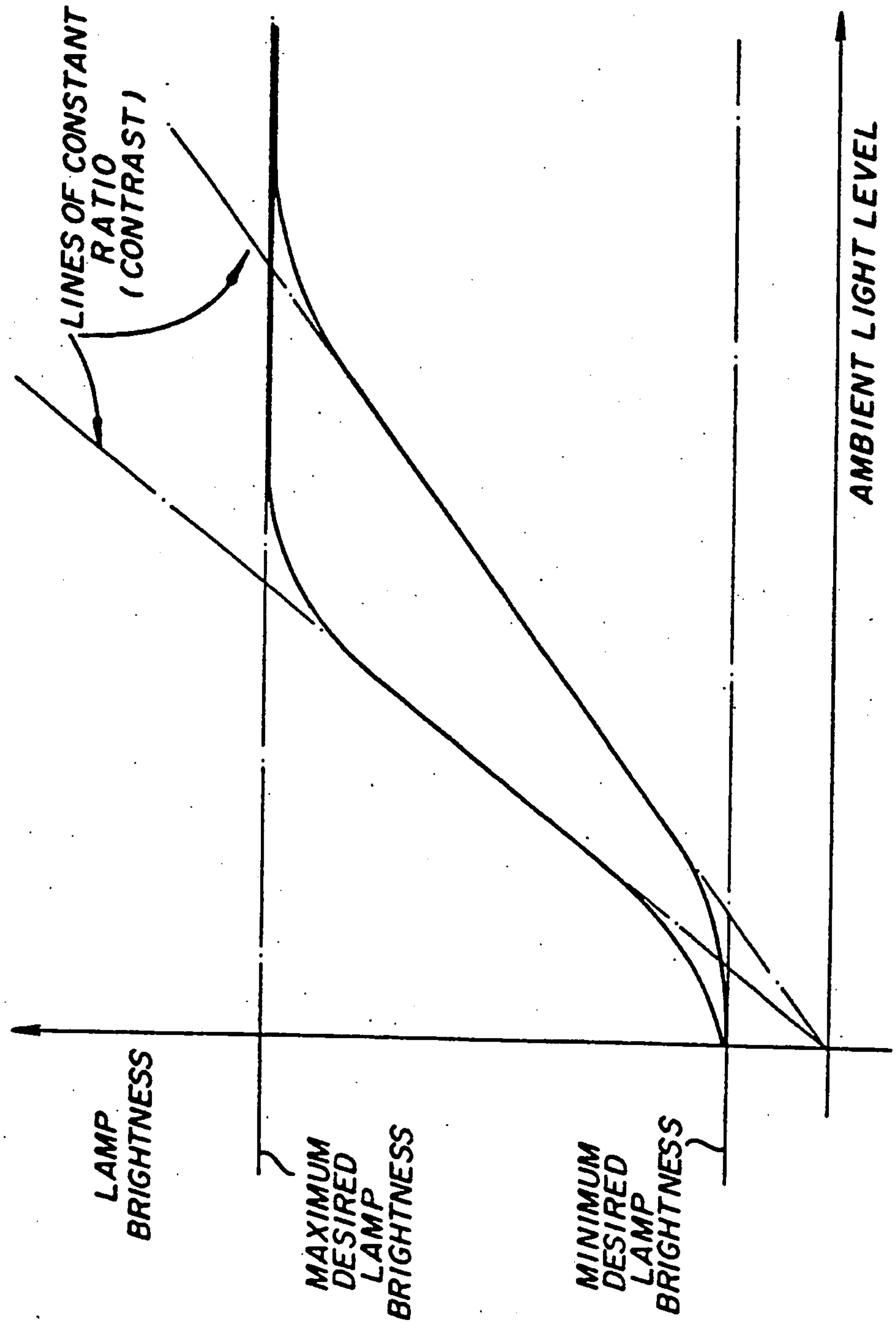

LINES OF CONSTANT RATIO (CONTRAST)
AMBIENT LIGHT LEVEL
LAMP BRIGHTNESS
MAXIMUM DESIRED LAMP BRIGHTNESS
MINIMUM DESIRED LAMP BRIGHTNESS

FIG. 3

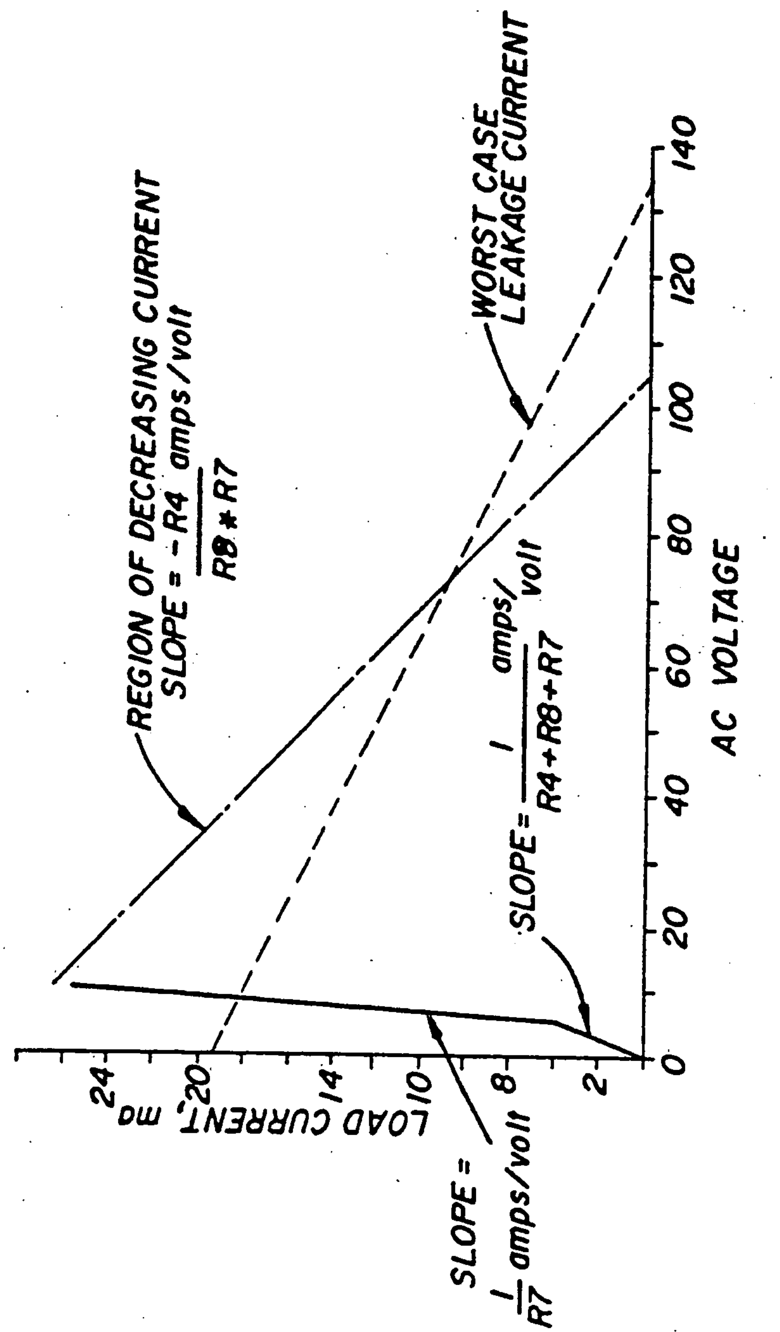

REGION OF DECREASING CURRENT
SLOPE = -R4 / R8 * R7 amps/volt
WORST CASE
LEAKAGE CURRENT
SLOPE = 1 / R4+R8+R7 amps/volt
SLOPE = 1/R7 amps/volt
LOAD CURRENT, ma
24
20
14
10
8
2
0
20
40
60
80
100
120
140
AC VOLTAGE

FIG. 4

POWER SUPPLY DYNAMIC LOAD FOR TRAFFIC AND PEDESTRIAN SIGNAL

BACKGROUND OF THE INVENTION

The dynamic load circuit of the invention finds particular utility in the power supply for a traffic or pedestrian crossing signal, or for other types of signals, for attenuating the effects of leakage currents when a particular signal is switched to its off state.

As is well known, pedestrian traffic signals usually comprise a first luminescent tubular lamp which is energized to indicate a "WALK" signal and a second luminescent lamp which is energized to indicate a "DONT WALK" signal. These lamps are alternately switched on and off, usually by solid state switches, such as triac switches. However, such switches exhibit leakage currents. Such leakage currents are usually of the order of 20 mils, which do not result in appreciable voltages except when fluorescent or neon lamps are used.

It is usual for pedestrian and traffic lights to use "green" monitors which sense a condition where two "walk" or "go" signals are energized at the same time at the same inter section for interesecting streets. Such a condition could cause a disaster, and it is a function of the "green monitors" to switch the lights to their flashing mode should that condition occur.

When neon or fluorescent tubes are used in the pedestrian or traffic lights, the voltages generated by the leakage current through the triac switches are sufficient to activate the "green" monitors which mistakenly react thinking the particular circuit is on, when it actually is off.

The dynamic load circuit of the present invention is such that when the triac switches are off, the leakage current sees a relatively low impedance to ground so that no excessive voltage builds up. However, when the triac switches are on, and the input voltage ramps up, the impedance of the dynamic load circuit immediately increases, effectively taking the load circuit out of the main circuit.

SUMMARY OF THE INVENTION

The dynamic load circuit of the invention is designed so that the current shunted to ground is high at low voltages and low at high voltages. This requires that the impedance of the circuit be negative over a portion of its operating region so that current will decrease with increasing voltage over that region. This is accomplished by the provision of a two stage inverting D.C. amplifier with a low impedance load and a defined offset voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B show a circuit diagram of a power supply constructed in the manner described in Copending Application Ser. No. 514,274, filed Apr. 25, 1990, and which includes a dynamic load circuit constructed in accordance with the concepts of the present invention in one of its embodiments; and

FIGS. 2, 3 and 4 are curves useful in explaining the operation of the circuit of FIGS. 1A and 1B.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

The solid state power supply illustrated in the circuit of FIGS. 1A and 1B accomplishes the objective of the invention disclosed in the Copending Application by

utilizing two light sensors R_1 and R_a one to monitor lamp brightness and the other to monitor ambient light. The light brightness monitor sensor R_1 is the key element since lamp efficiency varies widely so that lamp brightness cannot be accurately established by an open loop control of the power delivered to the lamp.

The basic purpose of the power supply shown in FIG. 1 is to provide a variable source of high voltage power for a luminescent lamp in such a manner that the power delivered is automatically adjusted to a level such that the brightness of the lamp is maintained in a constant ratio with respect to the ambient light falling on the lamp.

The power of FIGS. 1A and 1B is made up of six functional components:

1. Rectifier bridge and storage capacitor circuit.
2. Start-up supply circuit.
3. Dynamic load circuit.
4. Operating supply circuit.
5. Sensor bridge circuit.
6. Switching regulator circuit.

The rectifier bridge is made up of a fuse F1, and four diodes Cr1–CR4, together with a capacitor C1. The rectifier bridge is connected to an appropriate source of 60 Hz alternating current power through a fuse F1. Fuse F1 may, for example, be a 1.5 amp fuse. Diodes Cr1–CR4 may each be of the type designated 5395, and capacitor C1 may be a 60 microfarad capacitor. The fuse F1, diodes CR1–CR4, and capacitor C1 form a straightforward full-wave recitifed, capacitive filtered DC power supply with nominal output voltage of 160 volts DC at an input of 115 volts AC.

The switching regulator is designed around an integrated circuit U1 which may be of the type designated SGS3526. Integrated circuit U1 functions as a fixed frequency pulse width modulator. The output of the switching regulator is connected to a primary winding P1 of a power output transformer T1. The lamp to be energized by the power supply is connected across the secondary S1 of the output transformer. The power delivered to the lamp is modulated by varying the width, or duty cycle of the output pulses from integrated circuit U1, while the frequency of the pulses remains constant.

The integrated circuit U1 has two switch outputs, designated respectively "Out A" and "Out B" which appear at pins 13 and 16. These outputs are applied to the primary winding P1 of output transformer T1 through MOSFET output power devices Q4 and Q5. These power devices may be of the type designated 445-500A, and are rated at 500 volts and 4 amperes. Output A and output B of integrated circuit U1 are switched alternately so that the power output transformer T1 is driven in a push-pull mode. Transformer T1 is designed to have a high output voltage and a high output reactance in order to match the luminescent lamp drive requirements.

The frequency at which the outputs appearing at pins 13 and 16 are switched is constant and is fixed by the values of resistors R13 and R17 and capacitor C5. In the illustrated embodiment, resistor R13 has a value of 10 kilo-ohms, resistor R17 has a value of 22 ohms, and capacitor C5 has a value of 0.0022 microfarads. In the illustrated circuit, the nominal frequency is set at approximately 30 kH. As shown, pins 13 and 16 are connected to the respective gate electrodes of MOSFETs Q4 and Q5 through 100 ohm resistors R15 and R16, and

the source electrodes of the MOSFETs are connected to ground through a common 0.1 ohm resistors R18. Resistors R15 and R16 limit the maximum gate currents of the MOSFETs. MOSFETs Q4 and Q5 are of the type designated BUK445-500A.

The percentage of time that each of the outputs at pins 13 and 16 of integrated circuit U1 on, that is the duty cycle, varies between 0 and something less than 50%. The maximum duty cycle of a single output is constrained to less than 50% in order to eliminate the possibility that both out put devices can be on at the same time. This is accomplished by establishing a dead time during which neither output can be on. The dead time is set by the value of resistor R17 in conjunction with the value of capacitor C5. The voltage at pin 10 (Ct) is a sawtooth waveform varying between two voltages with a frequency of twice the output frequency of the integrated circuit. The fall time of the sawtooth waveform is the dead time, as shown in the curve of FIG. 2. As shown in FIG. 2, the rise time of the sawtooth waveform is formed by the values of resistor R13 and capacitor C5.

The output pulse width is determined by comparing the sawtooth waveform at pin 10 with the voltage at the compensation pin 3. One or the other of the outputs appearing at pins 13 and 16 is turned on whenever the upward ramping voltage at pin 10 (Ct) is less than the voltage at the compensation pin 3. Thus, if the voltage at the compensation pin 3 is less than the minimum voltage at the Ct pin 10, the outputs will never go on. If the voltage at the compensation pin 3 is greater than the maximum voltage at Ct pin 10, the outputs will only be off during the dead time, that is, the output duty cycle will be at a maximum. For values at the compensation pin Ct between these extremes, the duty cycle will vary linearly with the voltage at Ct pin 10.

The integrated circuit U1 contains an error amplifier which is of the trans-conductance type which has a very high output impedance and in which the output current is proportional to the input error voltage applied to pins 1 and 2 of the integrated circuit U1. The output of this error amplifier is connected to the compensation pin 3 which, in turn, is connected to a grounded 1 microfarad capacitor C4. The voltage at the compensation pin is therefore proportional to the integral of input error, and this voltage continually increases or decreases as necessary until the error input goes to zero.

A 51 ohm resistor R14 is connected between pins 14 and 17 of integrated circuit U1 to limit feed-through currents within the integrated circuit which are created when the out puts are switched because of excessive internal device turnoff time.

Rectifiers CR6 and CR7 are connected to a secondary winding S2 of power transformer T1, and to pin 17 of integrated circuit U1. These rectifiers may be of the type designated IN4934. The rectifiers, together with capacitors C6 and C7 provide a DC voltage of 8-20 volts to power the integrated circuit U1. Capacitor C6 may have a value of 0.1 microfarad and capacitor C7 may have a value of 33 microfarads.

The rectifier bridge described above is connected to a start-up power supply. The start-up power supply is necessary because the integrated circuit U1 cannot become active until it is supplied with power, and the operating power supply cannot supply power until the integrated circuit is active. Accordingly, the start-up power supply shown in FIG. 1A is required.

The start-up power supply consists of a MOSFET Q1, whose gate electrode is driven from a voltage divider made up of a resistor R1 and resistor R2. Resistor R1 may have a resistance of 120 kilo-ohms and resistor R2 may have a resistance of 12 kilo-ohms. Resistor R1 is connected to the 160 volt DC power line A from the rectifier bridge described above. The values of the resistors R1 and R2 are selected so that the voltage at the source electrode of the MOSFET Q1 is sufficient to turn on the integrated circuit U1 at the desired alternating current input voltage, but less than the voltage which is generated by the operating power supply once the integrated circuit is turned on. This insures that the startup power supply, which is very inefficient, only serves to start the integrated circuit U1.

Once the integrated circuit U1 is started, the operating power supply raises the source voltage of the MOSFET Q1 and turns it off leaving the start-up power supply inactive. Resistor R3 which connects the drain electrode of MOSFET Q1 to the 160 volt DC line A provides a current limiting function to protect the MOSFET Q1 in the event of an abnormally high load which might be caused by an inadverent short circuit to ground. MOSFET Q1 may be of the type designated MTP4N50.

The sensor bridge shown in FIG. 1B is primarily responsible for establishing and maintaining the brightness of the lamp driven by the power output transformer T1. The sensor bridge circuit incorporates three sensing elements, namely photoresistors R1 and Ra, and a thermistor RT. The photoresistors R1 and Ra have the property that their resistance is a strong negative function of the intensity of light falling on their faces. One of the photoresistors R_1, is used to monitor the brightness of the lamp itself, and it is mounted adjacent to the lamp for that purpose. The other photoresistor Ra is used to monitor the brightness of the incident ambient light, and it is appropriately mounted in a position to perform that function. The third sensing element RT, as mentioned, is a thermistor, and it is used to monitor the temperature of the lamp. The thermistor, likewise, is mounted in an appropriate position to perform its intended function.

As illustrated in FIG. 1B, the sensors R1 and Ra are connected, together with a 750 ohm resistor R1 in series between pin 18 (V_{ref}) and ground. The resistor R11 and sensor Ra are shunted by a 0.1 microfarad capacitor C3 and a resistor R12. The resistance of resistor R12 may be, for example, 12 kilo-ohms where a white fluorescent lamp is being energized, or a resistance of 24 kilo-ohms in the event a neon lamp is being powered by the system.

Pin 18 is connected to a 5 kilo-ohm potentiometer R9 which, in turn, is connected to a grounded 5.1 kilo-ohm resistor R10. The junction of sensor R1 and resistor R11 is connected to pin 2 of the integrated circuit U1 (−error), and the movable arm of potentiometer R9 is connected to pin 1 (+error). Thermistor RT is connected across resistor R10, and is shunted by a 0.1 microfarad capacitor C2.

Sensors R1 and Ra, and potentiometer R9 and resistor R10 are connected essentially as a bridge whose voltage is monitored by the error amplifier in the integrated circuit U1. The bridge is balanced, and the error voltage is zero, when the ratio of the resistances of the photosensors R1 and Ra is equal to the resistances of potentiometer R9 and resistor R10. It will be appreci-

ated that potentiometer R9 and resistor R10 form a reference voltage for the sensors R1 and Ra.

An error in the direction of a low ratio of lamp brightness to ambient brightness causes the output of the error amplifier in integrated circuit U1 to ramp up. This, in turn, causes the output duty cycle and consequently the power delivered to the lamp to increase. The lamp power will increase until the bridge is balanced and the error voltage is reduced to zero or, alternately, until the power reaches its maximum value, as shown by the curves of FIG. 3.

Alternately, if the bridge is unbalanced in the direction of a high ratio of lamp brightness to ambient brightness, the error amplifier in integrated circuit U1 will ramp down, reducing the output duty cycle and the lamp power until the bridge is again balanced. Accordingly, it can be seen that the bridge is configured to maintain the lamp power at that value required to establish a constant ratio between the resistances of photosensors R1 and Ra, and consequently a constant ratio between lamp brightness and ambient brightness. The particular ratio is set by the potentiometer R9 which establishes the reference voltage at pin 18 (V_{ref}).

The only function of capacitors C2 and C3 is to reduce ripple and noise at the bridge output to a level which is tolerable to the error amplifier in the integrated circuit U1. Resistors R12 and R11 are incorporated to limit the maximum and minimum lamp brightness, as represented by the curves of FIG. 3. Resistor R12 is used to set the minimum light brightness, which is necessary if the contrast were maintained at a constant level down to total darkness, the lamp would also be totally dark. In general, a minimum lamp brightness is required, no matter how low the ambient light level may become. Similarly, resistor R11 is incorporated for the establishment of a maximum light brightness which permits the power requirement to be limited in the case of extremely high ambient light levels.

The function of thermistor RT is to limit the upper temperature of the lamp. The power deliverable to the lamp is significantly higher than that which the lamp can handle at normal ambient temperatures in order to allow the rather dramatic fall off in lamp efficiency which occurs at low temperature. If, for any reason, this power level were to be delivered to the lamp for a long period of time and at high ambient temperatures, the lamp would overheat and turn off. The function of thermistor RT is to reduce the command contrast ratio when the lamp temperature approaches its maximum operating temperature.

The dynamic load circuit of the present invention is shown in FIG. 1A, and it enables the power supply to present a low impedance to the line power source when the input power is turned off. This is so that external switch leakage current does not create appreciable voltages at the input terminals.

The dynamic load circuit includes a 200 kilo-ohm resistor R4, a Zener diode CR5 and a 13 kilo-ohm resistor R5 connected between the 160 volt DC line A and ground. The Zener diode may be of the type designated IN753A, and may have a rating of 10 volts. The junction of the Zener diode and resistor R5 is connected to the base of an NPN transmitter Q2, which may be of the type designated 2N4401. The emitter of transistor Q2 is grounded, and its collector is connected to line A through a 200 kilo-ohm resistor R6. The collector of transistor Q2 is also connected to the gate of a MOSFET transistor Q3 which may be of the type designated MTB4N50. The drain of transistor Q3 is connected to line A, and the source is connected to a 220 ohm grounded resistor R7. The junction of Zener diode CR5 and resistor R4 is connected through a 13 kilo-ohm resistor R8 to the junction of resistor R7 and the source of MOSFET Q3.

The dynamic load circuit is best viewed as a two terminal device with a unique volt/ampere characteristic. The circuit is configured such that the current shunted to ground is high at low voltages and low at high voltages. This requires that the impedance of the circuit be negative over some portion of its operating region, that is, the circuit is such that the current decreases over part of its operating region with increasing voltage. This characteristic is shown, for example, in the curve of FIG. 4.

The foregoing is accomplished by creating a two-stage inverting DC amplifier with a low impedance load and a defined off-set voltage. Transistor Q2 and resistor R6 form a grounded emitter high gain inverting stage, and MOSFET Q3 which forms the second stage is a source follower with low output impedance and a gain of one. Zener diode CR5 establishes the offset voltage. Resistor R4 forms the amplifier input resistor, and resistor R8 forms the feedback resistor, whereas resistor R7 forms the load resistor.

For high voltages, in the linear negative impedance operating region, transistor Q1 is neither cut off nor saturated, and the closed loop gain of the amplifier is approximately equal to $-R8/R4$. In this region, the dominant current in the circuit is the current through load resistor R7 which is proportional to the amplifier voltage. Now, since the amplifier output voltage with increasing input voltage, the total circuit current must necessarily decrease as the input voltage increases.

At low input voltages the transistor is cut off and the output voltage follows the input voltage minus the threshold voltage of MOSFET Q3. For inputs between zero and the threshold voltage of MOSFET Q3, the current increases slowly with input voltage at a proportionality factor of R4+R8+R7 (FIGURE). Once the threshold voltage of the MOSFET Q3 is exceeded the conductance of the circuit is positive and equal to that of load resistor R7, that is, the current increases quickly with the increasing voltage at a proportionality factor of

$$\frac{1}{R_7}.$$

The values of the various resistors R4, R5, R6, R7 and R8 and of Zener diode CR5 are selected to insure that, over the input voltage region which falls between the maximum allowable off-state voltage and the point at which the power circuit itself turns on, the current required by the dynamic load is greater than that of the off-state switch leakage current from the external solid state control switch.

In the foregoing manner, the dynamic load circuit achieves its desired purpose of insuring that the power supply presents a low impedance to the line power source when the power is off, so that external alternating current switch leakage current cannot create appreciable voltages at the input terminals.

The invention provides, therefore, an improved power supply for the luminescent lamp of a pedestrian or traffic signal which attenuates leakage current from

the external switches when the particular lamp is intended to be turned off, so as to prevent the build-up of spurious voltages within the power supply when the power supply is in its off state.

It will be appreciated that while a particular embodiment of the invention has been shown and described, modifications may be made. It is intended in the claims to cover all modifications which come within the true spirit and scope of the invention.

I claim:

1. A dynamic load circuit having first and second input terminals for receiving input voltages, said dynamic load circuit including: a load resistor; circuit means connected to said input terminals and to said load resistor and having a first operating region exhibiting positive impedance for relatively low input voltages and a second operating region exhibiting negative impedance for relatively high input voltages, with the current through said load resistor increasing for increases of said relatively low input voltages and decreasing for increases of said relatively high input voltages, said first circuit means comprising a two-stage inverting direct current amplifier formed of a high gain inverting first stage and a unity gain second stage; and including a circuit connected to said first stage for establishing a defined offset voltage; said high gain invertor first stage comprising a transistor having its emitter connected to the first input terminal and a first resistor having its collector connected to a said input terminal, and including a second resistor, a Zener diode and a third resistor series-connected across said input terminals, the junction of said diode and said third resistor being connected to the base of said transistor, said first resistor forming an input resistor for the amplifier, and said Zener diode establishing said defined off-set voltage.

2. The dynamic load circuit defined in claim 1, in which said second stage comprises a MOSFET having its drain connected to said second input terminal, and a fourth resistor connecting its source to said first input terminal, and having its gate connected to the collector of said transistor, and a fifth resistor connected between the source of said MOSFET and the junction of said second resistor and said Zener diode to form a feed back for the amplifier.

* * * * *

EXHIBIT D

Power Supply Cookbook

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whose amplitude is the magnitude of the input voltage and whose duty cycle is controlled by a switching regulator controller. Once the input voltage is converted to an ac rectangular waveform, the amplitude can be stepped up or down by a transformer. Additional output voltages can be derived by adding secondaries to the transformer. Ultimately these ac waveforms are then filtered to provide the dc output voltages.

The controller, whose main purpose is to maintain a regulated output voltage, operates very much like a linear-style controller. That is, the functional blocks, voltage reference, and error amplifier are arranged identically to those in the linear regulator. The difference is that the output of the error amplifier (the error voltage) is then placed into a voltage-to-pulsewidth converter stage prior to driving the power switches.

There are two major operational types of switching power supplies: the *forward-mode* converter and the *flyback-mode* converter. Although their arrangements of parts are subtly different, their operation is very different and each has advantages in certain areas of application.

3.1.1 The Forward-mode Converter

Forward-mode regulators form a large family of switching power supply topologies. They can be recognized by an L–C filter directly after the power switch or after the output rectifier on the secondary of a transformer. A simple form of the forward-mode regulator can be seen in Figure 3–1. This is called the *buck regulator*.

Its operation can be seen as analogous to a mechanical flywheel and a one-pistoned engine. The L–C filter, like the flywheel, stores energy between the power pulses of the driver. The input to the L–C filter (*choke input filter*) is the chopped input voltage. The L–C filter averages this duty-cycle modulated input voltage waveform. The L–C filtering function can be approximated by

$$V_{out} \approx V_{in}(\text{duty cycle}). \tag{3.1}$$

The output voltage is maintained by the controller by varying the duty cycle. The buck converter is also known as a *step-down converter*, since its output must be less than the input voltage.

The operation of the buck regulator can be seen by breaking its operation into two periods (refer to Figure 3–2). When the switch is turned on, the input voltage is presented to the input of the L–C filter. The inductor current ramps linearly upward and is described as

$$i_{L(on)} = \frac{(V_{in} - V_{out})t_{on}}{L} + i_{init}. \tag{3.2}$$

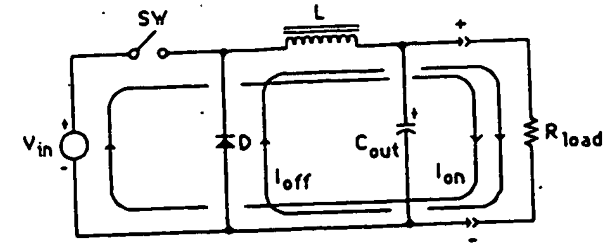


Figure 3–1 A basic forward-mode converter (buck converter shown).

3. Pulsewidth Modulated Switching Power Supplies

Although pulsewidth modulated (PWM) switching power supplies have been around for a long time, it was not until the mid-1970s that they became more accepted and broadly applied. Switching power supplies offer many advantages over linear regulators, but they are also much more complicated to design.

The major advantages that can be realized over a linear power supply are a higher integration of power functions at a lower weight, and a consistently higher efficiency. The disadvantages are higher RFI emissions, and the fact that they are more difficult to design and hence require a longer design period. The designer starting his or her first complicated design (more than a board-level regulator), should expect about a seven-month design–debug period until a production-grade design can be released. This book provides a shortcut method of reducing this time by providing to the designer just the right information needed for each phase of the design.

Many of the technologies involved in the design of switching power supplies are unfamiliar to the typical design engineer. This can easily be explained by looking at the technologies being applied in modern product design. They center around microprocessors and digitizing of analog signals for use in microprocessors. Little of this technology is applicable in switching power supply design. Engineers, whether they want to or not, will learn some of these basic technologies in the process of the design. Many engineers find switching power supplies challenging and exciting, as being a peculiar combination of digital, analog, and RF. Hidden behind the schematic of every successful switching power supply are hundreds of puzzles, trade-offs, and frustrated moments.

3.1 The Fundamentals of PWM Switching Power Supplies

The operation of switching power supplies can be relatively easy to understand. Unlike linear regulators, which operate the power transistor in the linear mode, the PWM switching power supply operates the power transistors in both the saturated and cutoff states. In these states, the volt–ampere product across the power transistor is always kept low (saturated, low-V/high-I; cutoff, high-V/no-I). This product within the power device is the loss within all the power semiconductors.

This more efficient operation of the PWM switching power supply is achieved by "chopping" the direct current (dc) input voltage into pulses

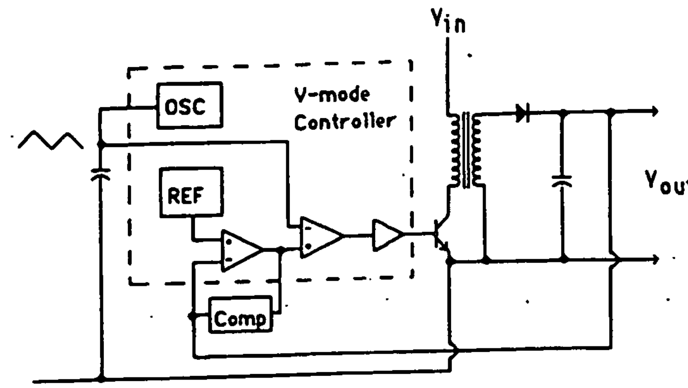


Figure 3-37 Voltage-mode control.

voltage error amplifier that compares the amplifier's output with the ramp voltage across a timing capacitor. Voltage-mode control has two shortcomings: it cannot protect against instantaneous overcurrent conditions in the power switch due to core saturation, and it exhibits a sluggish input transient response. The control ICs also typically have a bipolar-type output driver not readily suitable for power MOSFETs.

Current-mode control includes an ac current feedback loop in addition to the voltage feedback loop. It can be recognized by the output of the error amplifier being input into a comparator that compares the error voltage against the instantaneous power switch current. Now the controller is able to sense an impending core saturation condition or a voltage surge on the input. Hence, a current-mode controlled switching power supply is more robust and can withstand many factors that formerly caused a failure within the supply. The current-mode controller can be seen in Figure 3-38.

The third family of controllers are the variable frequency controllers. These are either *fixed on-time, variable off-time* or *fixed off-time, variable*

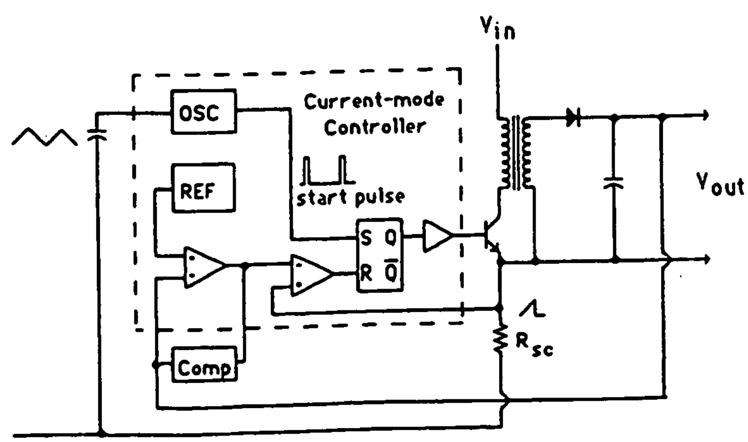


Figure 3-38 A current-mode controller.

on-time. These are typically used for quasi-resonant switching power supplies but can also be used in PWM supplies. Here the error amplifier drives a voltage-controlled oscillator (VCO), which is followed by a one-shot timer. These methods of control are variations on the voltage-mode control and therefore have a poor input transient response characteristic. Three PWM control ICs do use a variable frequency method of control—the uC78S40, the MC34063, and the MC34163. The *gated oscillator* method turns on with fixed pulsewidths that can be overridden by an overcurrent condition and the off-time is used to control the output voltage.

One last factor in the selection of a controller IC is whether it has the power transistor integrated on the same die. The latest developments in power technology are bringing ICs with 0.5–5 A power switches on-board. This eliminates the need for an external power switch and usually saves money. Breakdown voltages of up to 800 V are now available.

Selection of the controller should be based upon the needs of the application. That is, what features would benefit the product and which features render that IC useless? Check carefully items such as low-voltage inhibits on the IC; a 16 V low-voltage inhibit circuit is useless for an application operating from 12 V, and so on. Table 3–7 includes the most popular switching power supply control ICs. For details of their application, refer to the respective manufacturers' data sheets.

3.9 Designing the Voltage Feedback Circuit

The only function of the voltage feedback loop is to hold the output voltage(s) at a constant value. Complications arise in areas such as transient load response, accuracy of the output(s), multiple outputs, and isolated outputs. All of these individually can be nightmares for the designer, but if the design approaches are understood then each factor can be easily addressed.

The heart of the voltage feedback loop is a high-gain operational amplifier called an *error amplifier*, which is nothing more than a high-gain amplifier that enhances the difference between two voltages and creates an error voltage. In power supplies one of these voltages is a reference voltage and the other represents the level of the output voltage. During operation, the output voltage presented to the other input to the error amplifier should be divided down to a voltage identical in value to the reference voltage in order to create a "zero error" output on the error amplifier.

The major design issues surrounding the error amplifier are that it should have a high gain at dc, which promotes good output load regulation, and have a good high-frequency response, which promotes good transient load response. These issues come under the area of feedback loop compensation, which is covered in detail in Appendix B.

An example of an elementary voltage feedback application is the nonisolated, single-output switching power supply. If we neglect the error amplifier compensation, then the design is quite simple. Let us examine a situation where a 5 V output is regulated and a 2.5 V reference is provided within the control IC. This can be seen in Figure 3–39.

To begin the process, one decides how much *sense current* is to be drawn through the output voltage resistor divider. For the sake of reasonable

Appendix C. Power Factor Correction

C.1 Power Factor Correction

Power factor correction is becoming a very important area in the power world. Adding more generating capacity to the world's electrical pool is very costly and would consume additional resources. One method of creating about 30 percent excess generating capacity is to use the ac power more efficiently through the broad use of power factor correction. Motors, electronic power supplies, and fluorescent lighting consume the majority of power in the world and each of these would benefit from power factor correction. In the mid-1990s, many of the countries of the world are going to adopt requirements for power factor correction for the new products marketed within their borders. The added circuitry will add about 20–30 percent to the cost of power supplies, but the near-term energy savings will greatly outweigh the initial costs.

The term "power factor" in the field of power supplies is a slight departure from the traditional usage of the term, which applied to reactive ac loads, such as motors, powered from the ac power line. Here, the current drawn by the motor would be displaced in phase with respect to the voltage. The resulting power being drawn would have a very large reactive component and little power is actually used for producing work.

In switching power supplies, the problem lies in the input rectification and filter network. The typical input circuit and its associated waveforms are shown in Figure C-1. As one can see, the input rectifiers can only conduct current when the ac line voltage exceeds the voltage on the bulk input filter capacitor. This typically occurs within 15 degrees of the crest of the ac voltage waveform. The result is current pulses that are 5–10 times higher than the expected average current draw. This also can lead to distortion of the ac voltage waveform and an imbalance of the three-phase power lines feeding the circuits. This causes a current to flow within the neutral line where no current flow is expected. Another drawback is that no current is drawn when the rectifiers are not conducting, thus throwing away a significant portion of the power system's energy capability.

Power factor correction circuits are intended to increase the conduction angle of the rectifiers and to make the ac input current waveform sinusoidal and in phase with the voltage waveform. The input waveforms can be seen in Figure C-2. This means that all the power drawn from the power line is real power and not reactive. The net result is that the peak and rms current drawn from the line is much lower than that drawn by the capacitive input filter circuit traditionally used.

Active power factor correction (PFC) circuits take the form of non-transformer-isolated switching power supply topologies, such as buck, boost, and buck/boost. The buck topology in Figure C-3 produces an output dc

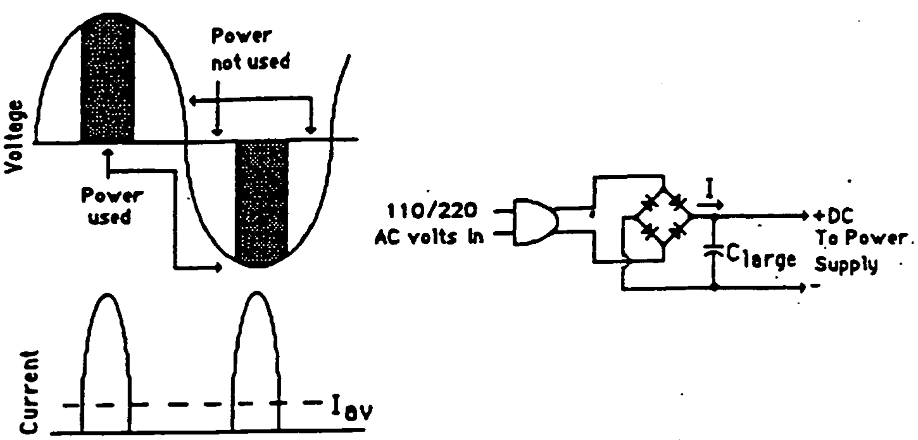


Figure C-1 The waveforms of a capacitive input filter.

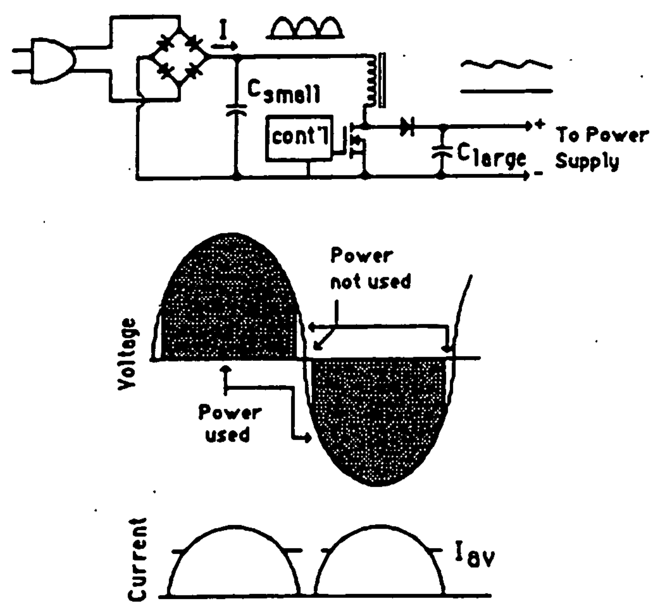


Figure C-2 Power factor corrected input.

voltage lower than found at its input whenever the PFC stage is operating. In other words, the output voltage is typically in the 30–50 VDC range. This can present a problem for higher-powered power supplies, which would then draw a large amount of current from the PFC circuit. The boost and the buck/boost topologies are popular within the field, since they produce a higher dc output voltage than the peak input voltage, which means lower average output currents. These are seen in Figures C–4 and C–5.

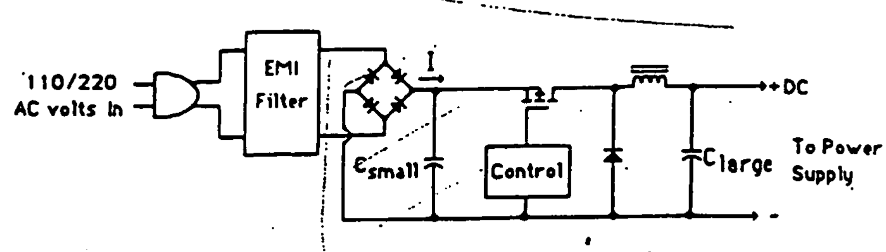


Figure C-3 A buck power factor correction circuit.

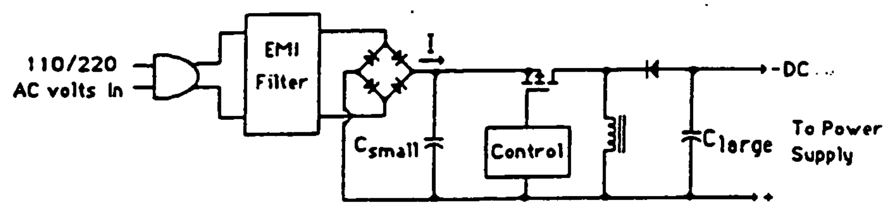


Figure C-4 A buck/boost power factor correction circuit.

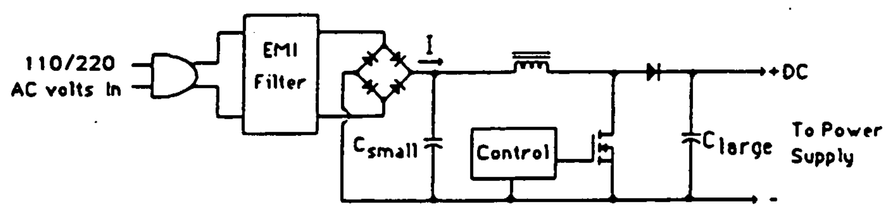


Figure C-5 A boost power factor correction circuit.

The buck/boost develops an output voltage that is negative with respect to the input ground following the rectifiers. The cascaded power supply and the PFC voltage-sense networks must work with a negative voltage, but the dc output voltage can be independent of the values of the rectified input ac waveform. The major disadvantage is the need for a high-side power switch and high breakdown voltage requirements for the semiconductors. The boost topology has become the most popular. It has a low-side power switch that is easy to drive. Its only restriction is that the dc output voltage must be higher than the highest expected ac crest voltage. This means that for a PFC circuit to be useful in all power grids in the world, the output voltage must be greater than 390 VDC, and will pass voltage surges onto the load. Otherwise, it requires the fewest parts and hence costs the least.

Control of the power factor correction stage is a point of debate and battling patents. There are three general methods of control centered around the basic current-mode control philosophy. The basic PFC controller takes the form shown in Figure C-6. There is a multiplier subcircuit inside the control IC that multiplies the instantaneous value of the input full-wave rectified voltage waveform with the output of the error amplifier. This

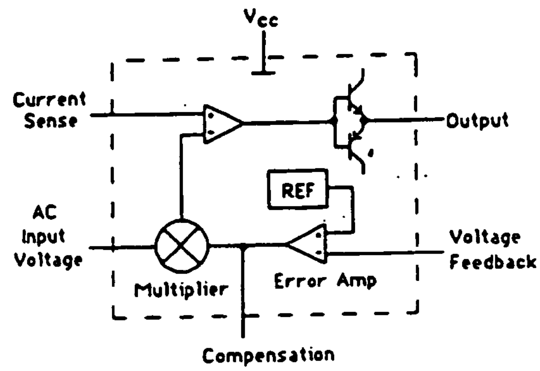


Figure C-6 A generalized typical power factor control IC.

produces a current limit signal that makes the input currents follow a sinusoidal waveshape. The sinusoidal switched current waveform envelope is then filtered by the input EMI filter to produce a 50–60 Hz input current waveform that is free of switching artifacts.

There are three main implementations in the control of PFC circuits: the fixed-frequency average current sensing method as implemented by Unitrode under the Pioneer Magnetics patent (UC3854); the fixed "on" time, peak current sensing method by Microlinear (UL4812); and the critical-conduction, peak current sensing method used by Silicon General (SG3561) and Motorola (MC34261). The latter two methods are variable-frequency methods of control. All the methods produce acceptable power factors as specified by the regulatory agencies at the time of the printing of this book. That situation may change if the requirements become tougher.

The inductor operating mode is a major consideration in designing a PFC circuit. The discontinuous mode of operation is typically used for power levels less than 200 W. It has high peak currents, which limits its use at the higher input power levels. For powers greater than 200 W, the continuous mode of operation is used. This lowers the peak currents seen by the power switch and output rectifier and is much easier to filter in the EMI filter since there are no rapid transitions in the input switched current waveforms. The only disadvantage is that the switching losses rise significantly because the power switch must force off the output rectifier at the beginning of each "on" time period. The choice of output rectifier (low T_{rr}) becomes critical to the operation of the PFC stage. Some gallium arsenide rectifiers under development may reduce this problem.

C.1.1 How the Power Factor is Specified

I strongly recommend engaging a third-party EMI testing house to test your company's products. The minimum level of test equipment required to test for the factors discussed is very expensive and there is a learning period involved.

The following discussion is based upon IEC555 prerelease drafts. The limits presented in this specification may change prior to its release. Also the United States and Canada are developing specifications of their own that

will probably follow the guidelines presented by IEC555 but may contain additional requirements. This is a developing field, so be aware of the most recent specifications at the time of your product release.

The real power delivered to a load is given by

$$P_{in} = V_{in} I_{in} \cos \phi \tag{C.1}$$

where

$$\phi = \text{Power Factor} = \frac{\text{Real power}}{\text{Real power} + \text{Reactive power}}. \tag{C.2}$$

In terms of strictly reactive passive loads, the power factor is the resulting phase between the voltage and the current waveforms. In power supplies though, it is the time during which the current is flowing that is related to the conduction angle of the input rectifiers. Power factor is measured from 0 to 1 where 1 means that all the power is used by the load. The typical capacitive input filter found in power supplies has an average power factor of 0.5–0.7.

In running the tests, a power analyzer must be used such as the Voltech PM1000, PM1200, or PM3000. An audio spectrum analyzer is also needed to measure the amplitude of the harmonic components of the ac current. The total input voltage and currents are given by

$$V_{rms(total)} = \sqrt{V^2_{fund(rms)} + V^2_{1(rms)} + V^2_{2(rms)} \cdots} \tag{C.3}$$

and

$$I_{rms(total)} = \sqrt{I^2_{fund(rms)} + I^2_{1(rms)} + I^2_{2(rms)} \cdots} \tag{C.4}$$

where the subscripts 1, 2, . . . indicate the harmonics. In power supplies the third harmonic is by far the largest and therefore the largest problem. Harmonics cause problems because, in a pure sense, only the fundamental current frequency produces real power, so that the reduction of harmonics produces a better power factor.

A term used in PFC is *total harmonic distortion*. This is defined as

$$\text{THD} = \frac{I_{1(rms)} + I_{2(rms)} \cdots}{I_{rms(total)}} \tag{C.5}$$

and it is an indication of the performance of a PFC circuit.

From the power analyzer or the spectrum analyzer, one can measure the amplitude values needed to verify compliance with the PFC specifications. At the time of publishing, only IEC555-2 had been made public and its limits are given in Table C-1. These limits must be measured with an LISN (line impedance stabilization network) as specified by the regulatory agencies. This makes the input power line a 50 Ω impedance and serves the basis of all of these tests. The test results are highly dependent upon the ac line impedance.

Some comments on the design of PFC circuits. First, the EMI filter is an integral part of any PFC circuit. It filters out the switching noise from the input current waveform. Without an EMI filter, your product will fail the EMI/RFI tests which are in addition to the power factor tests. Refer to Appendix E for the design of an EMI filter. Secondly, using a variac during the measurements will affect the input line impedance and thus affect the validity of the data you are trying to measure. Variacs usually make the data

Table C-1 IEC555-2 (1989) Harmonic Current Limits (Class A)

Harmonic	Absolute Limits (Amps RMS)
2	1.08
3	2.30
4	0.43
5	1.14
7	0.77
9	0.44
$15<n<39$	0.15(15/n)

better than it really is. Thirdly, all voltage measurements must be differential and use the specified current-measuring apparatus.

C.2 A Universal Input, 180 W, Active Power Factor Correction Circuit

This design example demonstrates the design process of a 180 W discontinuous-mode boost PFC circuit. It can be scaled to provide output powers up to 200 W. The PFC stage is designed to work from every residential ac power system in the world, that is, from 85 to 270 VRMS at 50 and 60 Hz without the need for a jumper.

Design specification

AC input voltage range:	85–270 VRMS
AC line frequencies:	50–60 Hz
Output voltage:	400 VDC ± 10 V
Input power factor at rated load:	>98 percent
Total harmonic distortion (THD):	Under IEC555-2 limits

Predesign considerations

Having a rating less than 200 W has many benefits for a power factor correction stage. The major benefit is that it can operate in the discontinuous mode. In higher-power PFC designs the continuous mode must be employed, which presents a significant loss within the circuit due to the reverse recovery time of the output rectifier. In fixed-frequency discontinuous-mode PFC controllers there is still a period when the circuit operates in the continuous mode ($V_{in}<$ approx. 50 V). By employing a *critical conduction-mode* controller, the designer can guarantee that the continuous mode is never entered.

The first consideration is to determine the peak ac input voltages.

110 V input:

$$V_{in(nom)} = 1.414(110\text{ V}) = 155.5\text{ V}.$$
$$V_{in(hi)} = 1.414(130\text{ V}) = 183.8\text{ V}.$$

240 V input (Britain—worst case):

$$V_{in(nom)} = 1.414(240\text{ V}) = 339.4\text{ V}.$$
$$V_{in(hi)} = 1.414(270\text{ V}) = 381.8\text{ V}.$$

The output voltage should be higher than the highest anticipated input peak crest voltage. The output voltage of the PFC stage is chosen to be 400 VDC.

The maximum value for the peak inductor current will occur at the crest voltage of the minimum expected ac input voltage. This is

$$\begin{aligned} I_{pk(max)} &= 1.414(2)(P_{out(rated)})/(\text{eff}_{est})(V_{in(min)rms}) \\ &= 1.414(2)(180\ \text{W})/(0.9)(85\ \text{V}_{rms}) \\ &= 6.6\ \text{A}. \end{aligned}$$

Inductor design

In designing the boost inductor, one would designate the point of reference as the crest voltage of the minimum expected ac input voltage. For any set of operating conditions with this method of PFC control, i.e., fixed load and ac input voltage, the "on" time pulsewidth remains constant over the entire half-sinusoid waveform. To determine the "on" time at the minimum peak ac input voltage one evaluates the following:

$$R = \frac{V_{out(dc)}}{\sqrt{2}V_{in\text{-}ac(min)}} = \frac{400\ \text{V}}{1.414(85\ \text{V}_{rms})}.$$

$$R = 3.3.$$

The maximum "on" time that occurs at this point is

$$T_{on(max)} = \frac{R}{f(1+R)} = \frac{3.3}{(50\ \text{kHz})(1+3.3)}$$

$$= 15.3\ \mu\text{s}.$$

The approximate maximum value of the boost inductor is

$$L \approx \frac{T_{on(max)}(\sqrt{2}V_{in\text{-}ac(min)})^2(\text{eff})}{2P_{out(max)}}$$

$$\approx \frac{(15.3\ \mu\text{s})(1.414(85\ \text{V}_{rms})(0.9)}{2(180\ \text{W})} \approx 552\ \mu\text{H}.$$

The power winding of the inductor (transformer) must support not only the maximum average input current but the output current as well. The wire gauge of the winding should be

$$I_{W(max\text{-}av)} = \frac{P_{out}}{\text{eff}(V_{in(rms)})} + \frac{P_{out}}{V_{out}}$$

$$= \frac{180\ \text{W}}{(0.9)(85\ \text{V}_{rms})} + \frac{180\ \text{W}}{400\ \text{V}} = 2.8\ \text{A}.$$

The wire gauge to accommodate this average current would be #17 AWG. I will use three strands of #20 AWG (which adds up to the same wire cross-sectional area), which is more flexible during the winding process and will help reduce the ac resistance of the winding due to the skin effect. Also, owing to the high voltages present within the same winding, I will be using quad-thickness insulation to reduce the threat of interturn arc-overs.

I am selecting a PQ core style. A major concern is the length of air-gap required for various core styles in unipolar applications. The larger air-gaps (>50 mils) cause excessive electromagnetic radiation into the immediate

environment, thus making it harder to filter RFI. To reduce the air-gap, one needs to find a ferrite core with the largest core cross-sectional area for a given core size. The PQ core has this characteristic. Referring to the $W_a A_c$ vs. power charts provided by Magnetics, Inc., the resulting PQ core part number is P-43220-XX. (XX is the gap length in mils.)

The approximate air-gap needed in the core is

$$l_{gap} \approx \frac{0.4\pi L I_{pk} \times 10^8}{A_c B_{max}^2}$$

$$\approx \frac{0.4\pi(552\,\mu H)(6.6\,A) \times 10^8}{(1.70\,cm^2)(2000\,G)^2} \approx 66 \text{ mils.}$$

Let us make the air-gap 50 mils, which is a custom air-gap. Magnetics has no problem with this practice and usually adds only a couple of percent to the core cost. The inductance factor (A_L) for this core with this gap is estimated at 160 mH/1000 turns (using a linear extrapolation of A_L reduction vs. air-gap length).

The number of turns needed for this inductance is

$$N = 1000\sqrt{\frac{0.55\,mH}{160\,mH}} = 59 \text{ turns.}$$

Checking to see whether the core will support this many turns (neglecting the auxiliary winding area):

$$\frac{A_W}{W_A} = \frac{(59)(0.471\,mm^2)}{47\,mm^2} = 59\%\text{—OK.}$$

Designing the auxiliary winding. The auxiliary winding will have the low-frequency (100–120 Hz) variation on its output peak rectified voltage, so the controller filter capacitor needs to be large to minimize the droop in the V_{cc} of the controller. The highest flyback-mode rectified voltage will occur at low input voltages and will be of the form

$$V_{aux} \approx \frac{N_{aux}(V_{out} - V_{in})}{N_{pri}}.$$

This ac waveform is seen in Figure C-7.

The MC34262 has a high-side driver clamp of 16 VDC, so in order to keep the high-side driver dissipation to a minimum, the peak voltage of the rectified auxiliary voltage should be around 16 V. Determine the turns ratio needed for this from

$$N_{aux} = \frac{(59)(16\,V)}{(400\,V - 30\,V)} = 2.5 \text{ turns.}$$

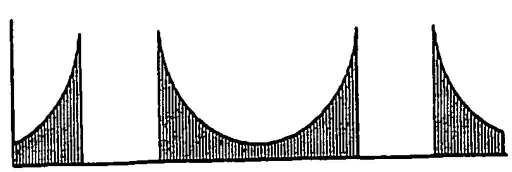


Figure C-7 The rectified ac waveform present on the auxillary winding.

I will make this winding three turns because of concern about low ac line operation. I will use one strand of #28 AWG heavy insulated magnet wire.

The capacitor needed to filter this voltage with approximately 2 V of voltage ripple is

$$C_{aux} \approx \frac{I_{dd} T_{off}}{V_{ripple}} = \frac{(25\text{ mA})(6\text{ ms})}{2.0\text{ V}}$$
$$= 75\ \mu\text{F—make } 100\ \mu\text{F @ 20 VDC.}$$

Transformer construction

The two-winding transformer will be constructed by first winding the 59 turns of the three strands of #20 AWG quad-thickness magnet wire onto the bobbin. Then place two layers of Mylar tape. Then the three turns for the auxiliary winding, and lastly three layers of Mylar tape. The internal layers of tape are to discourage any arcing that may occur due to the high voltages between the primary winding and the auxiliary winding. See Figure C–8.

Designing the start-up circuit

I will use a passive resistor for starting up the control IC and to provide current to the gate drive of the MOSFET. For the resistor I need to use two resistors placed in series, since the 370 V peak on the rectified input is comparable to the breakdown voltage of the resistors themselves. The start-up resistors will charge the 100 μF bypass capacitor and the subsequent energy stored in the capacitor must be sufficient to operate the control IC for the 6 ms before the worst-case rectified peak voltage from the auxiliary winding is available to operate the IC. The start-up voltage threshold hysteresis is 1.75 V minimum. Check whether the bypass capacitor is large enough to start the circuit before the turn-off threshold is reached:

$$V_{drop} = \frac{I_{dd} T_{off}}{C} = \frac{(25\text{ mA})(6\text{ ms})}{100\ \mu\text{F}}$$
$$= 1.5\text{ V—OK.}$$

I would like to keep the dissipation less than 1 W at the high input voltage line. To do this one needs to determine the maximum current that should pass through the start-up resistors.

$$I_{start} < \frac{1.0\text{ W}}{270\text{ V}_{rms}} = 3.7\text{ mA.}$$

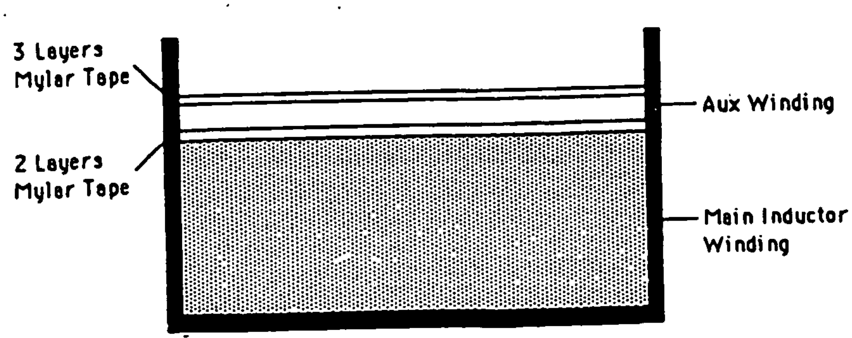


Figure C–8 Construction of the PFC boost inductor.

The total resistance is then

$$R_{start} = \frac{270\text{ V} - 16\text{ V}}{3.7\text{ mA}} = 68\text{ k}\Omega\text{ (min)}.$$

Make the total resistance about 100 kΩ or two 47 kΩ, $\frac{1}{2}$ W resistors.

Designing the voltage multiplier input circuit

The maximum specified limit of the input to the multiplier (pin 3) is 2.5 V. This level should be the peak value of the divided rectified input waveform at the highest expected ac input voltage at the crest of the sinusoid (370 V). If a sense current of 200 μA is selected at this point, the resistor divider becomes

$$R_{bottom} = \frac{2.5\text{ V}}{200\ \mu\text{A}} = 12.5\text{ k}\Omega\text{—make }12\text{ k}\Omega.$$

The true sense current is 2.5 V/12 K = 208 μA.

The top resistor becomes

$$R_{top} = \frac{370\text{ V} - 2.5\text{ V}}{208\ \mu\text{A}} = 1.76\text{ M}\Omega.$$

Make this two resistors in series each with a value of 910 kΩ.

The power ratings of these resistors are $P = (370\text{ V})^2/1.76\text{ M}\Omega$ or 0.8 W. Each resistor should have $\frac{1}{2}$ W power rating.

Design of the current sensing circuit

The current sense resistor should be sized in order to reach the 1.1 V current sense threshold voltage at the low ac input voltage. The value then becomes

$$R_{cs} = \frac{1.1\text{ V}}{6.6\text{ A}} = 0.33\ \Omega.$$

A leading edge spike filter of 1 kΩ and 470 pF will also be added before inputting the current signal to pin 4.

Designing the voltage feedback circuit

For the output voltage sense resistor divider, selecting the sense current as 200 μA, the lower resistor becomes

$$R_{bottom} = \frac{V_{ref}}{I_{sense}} = \frac{2.5\text{ V}}{200\ \mu\text{A}} = 12.5\text{ k}\Omega\text{—make }12.0\text{ k}\Omega.$$

This makes the true sense current 2.5 V/12 K = 208 μA.

The upper resistor is

$$R_{upper} = \frac{(400\text{ V} - 2.5\text{ V})}{208\ \mu\text{A}} = 1.91\text{ M}\Omega.$$

Make this resistor a 1 MΩ and a 910 kΩ resistor in series, each with a $\frac{1}{2}$ W rating.

The compensation of the voltage error amplifier should be a single-pole rolloff with a unity gain frequency of 38 Hz. This is required to reject the

fundamental line frequencies of 50 and 60 Hz. The feedback capacitor around the voltage error amplifier becomes

$$C_{fb} = \frac{1}{2\pi f R_{upper}} = \frac{1}{2\pi(38\text{ Hz})(1.82\text{ M}\Omega)}$$
$$= 0.043\ \mu\text{F, or } 0.05\ \mu\text{F}.$$

Designing the input EMI filter section

I will use a second-order, common-mode filter. The difficulty in considering an input-conducted EMI for this power factor correction circuit is its variable frequency of operation. The lowest instantaneous frequency of operation occurs at the crests of the sinusoid voltage waveform. This is where the core requires the longest time to completely discharge the core. The estimated frequency of operation was 50 kHz, so I will use this as an assumed minimum frequency.

A good starting point is to assume that I will need 24 dB of attenuation at 50 kHz. This makes the corner frequency of the common-mode filter

$$f_c = f_{sw} \times 10^{(\text{Att}/40)}$$

where Att is the attenuation needed at the switching frequency in negative dB.

$$f_c = (50\text{ kHz})10^{(-24/40)} = 12.5\text{ kHz}.$$

Assume that a damping factor of 0.707 or greater is good and provides a −3 dB attenuation at the corner frequency, and does not produce noise due to ringing. Also assume that the input line impedance is 50 Ω since the regulatory agencies use an LISN test that makes the line impedance equal this value. Calculating the values needed in the common-mode inductor and "Y" capacitors:

$$L = \frac{R_L \zeta}{\pi f_c} = \frac{(50\ \Omega)(0.707)}{\pi(12.5\text{ kHz})} = 900\ \mu\text{H}.$$

$$C = \frac{1}{(2\pi f_c)^2 L} = \frac{1}{[2\pi(12.5\text{ kHz})]^2(900\ \mu\text{H})} = 0.18\ \mu\text{F}.$$

Real-world considerations do not allow a capacitor of this large a value. The largest value capacitor that will pass the ac leakage current test is 0.05 μF. This is 27 percent of the calculated capacitor value, so the inductor must be increased to 360 percent of its former value in order to maintain the same corner frequency. The inductance then becomes 3.24 mH and the resultant damping factor is 2.5, which is acceptable.

Coilcraft offers off-the-shelf common-mode filter chokes (transformers) and the part number closest to this value is E3493. With this filter design I can expect a minimum of −40 dB between the frequencies of 500 kHz and 10 MHz. If later during the EMI testing stage I find I need additional filtering, I will add a third order to the filter design by using a differential-mode filter.

The schematic of the resulting power factor correction circuit is given in Figure C–9.

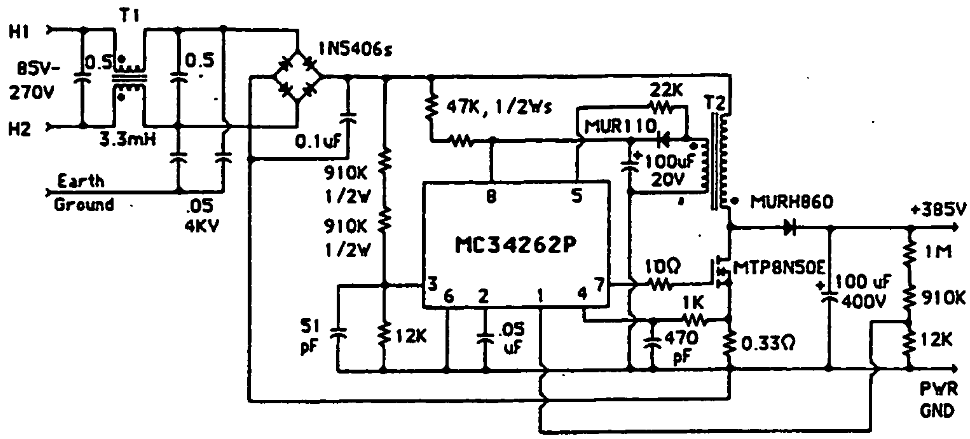


Figure C-9 The schematic for the 180 W power factor circuit (with EMI filter).

C.2.1 Printed Circuit Board Considerations

The unit in which this power factor correction circuit resides is going to be marketed everywhere in the world. The toughest safety requirements are issued by VDE in Germany. Here the *creepage* distance, or the distance that an arc must travel over a surface, is 4.0 mm for those signals that are opposite phases of an ac power line up to 300 V_{rms}. This means that there must be 4.0 mm spacing between traces of H1 and H2 (Hot and Neutral), and their rectified dc signals. Also there must be a 4.0 mm (minimum) surface distance between the windings on the input common-mode filter transformer and between high and low pins of the flyback inductor. The spacing of the 400 V output must be more than 4.0 mm from all other traces carrying less voltage. The creepage between any earth ground trace and the other traces must be more than 8.0 mm.

All current-carrying traces should be as wide and as short as possible. One-point grounding practices between the input, output, and low-level grounds should be done at the ground side of the current sense resistor.

magnetic material should be used in the enclosure construction. The material should be iron, steel, nickel, or Mu metal. For plastic enclosures, there are an assortment of conductive paints that can be used to add EMI/RFI shielding to the case. Also, any vent openings may need magnetic screening covering the openings.

The philosophy of any EMI shield is to encourage eddy currents to flow within the surfaces, thus dissipating the noise energy. Also, the overall enclosure should act as a gaussian enclosure where there is good electrical conduction totally around the enclosure. Thus removable hatches and enclosure members need very good electrical conduction around their peripheries. RF gasketing is sometimes used in particularly troublesome cases.

Leads that enter or exit the enclosure should ideally have their associated EMI filters at the point of entry or exit from the enclosure. Any unfiltered leadlengths that run within the enclosure will pick up noise inductively within the case and allow it to exit the case, thus making any EMI filtering less effective. Likewise, any unfiltered leads within the case will radiate any transients from outside the case into the case. This can adversely affect the static discharge susceptibility of the entire product.

E.4 Conducted EMI Filters

There are two types of input power buses: dc power buses, which are single-wire feeds such as found in automobiles and aircraft; and ac, two-, or three-wire feed systems such as found in ac power systems. The design of the EMI filter for dc systems is covered in Section 3.12 and takes the form of a simple *L–C* filter. All the noise is common-mode between the single power wire and the ground return. The ac filter is much more complicated to design because of the parasitic behavior of the components involved. All noise testing requires very expensive test equipment and is best done by a third-party EMI/RFI testing company.

To design a filter for the input of a switching power supply, the designer first needs to know which of the regulatory specifications is appropriate for

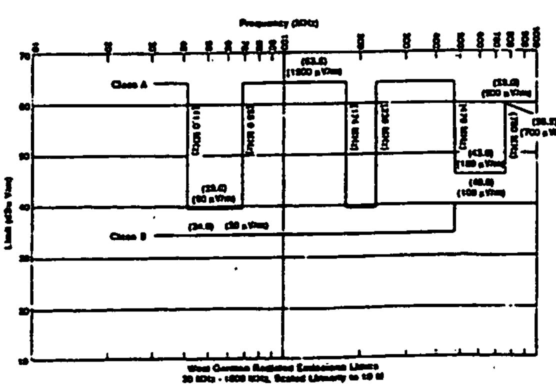


Figure E-4 VDE limits on radiated EMI.

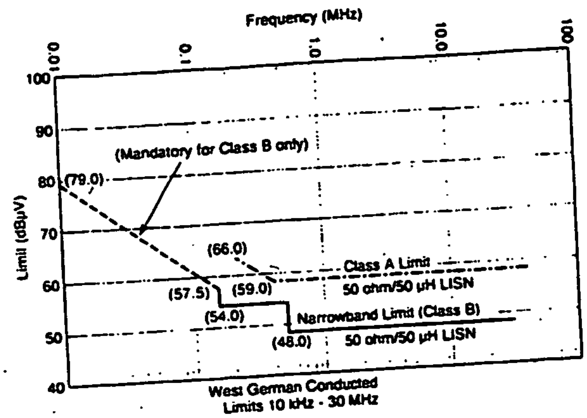


Figure E-5 VDE limits on conducted EMI.

the product. The specifications dictate the conducted and radiated limits that the entire product must meet in order to be sold into the market of interest. The marketing department should know which requirements are appropriate for the target market. It is always a good idea to design for the most stringent specification that is applicable to your market. For products to be sold in the European market, VDE has the most stringent limits. The VDE radiated limits are shown in Figure E-4, and the conducted limits are shown in Figure E-5. Class A limits are for equipment marketed in industrial environments and Class B are for residential markets.

The purpose of an input conducted EMI filter is to keep the high-frequency noise inside the case, so the appropriate noise source is mainly the switching power supply. Filtering on any of the input/output (I/O) lines is to keep noise from any internal circuit, like microprocessors, inside the case.

E.4.1 Design of the Common-mode Filter

The common-mode filter essentially filters out noise that is generated between the two power lines (Hot and Neutral or H1 and H2). The common-mode filter schematic is shown as part of Figure E-6.

In the common-mode filter the windings of the "transformer" are out of phase. The result is that the flux within the core cancels for those signals that are equal and opposite on the two power lines. However, any noise that is different between the two power lines is coupled through the core and "shorted out," thus not being allowed to pass through the filter.

The problem in designing the common-mode filter is that at high frequencies, where one wants and needs the filtering, the ideal characteristics of the components are compromised by their parasitic characteristics. The major parasitic is the *interturn capacitance* of the transformer itself. This is the small level of capacitance that exists in all windings, in which the voltage difference (volts/turn) between turns behaves like a capacitor. This capacitor, at high frequency, effectively acts as a shunt around the winding and allows more high-frequency ac current to go around the windings. The frequency at which this becomes a problem is above what is called the *self-resonance* of the winding. A tank circuit is formed between the winding

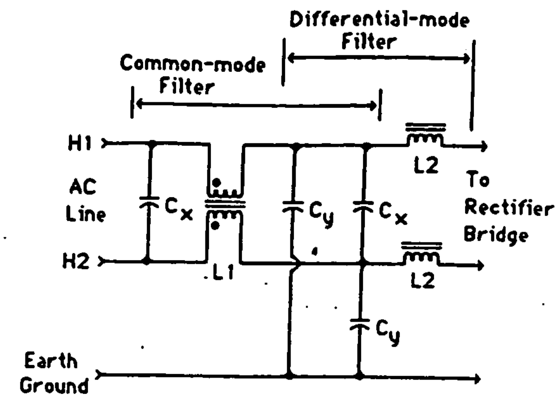


Figure E-6 A complete third-order, input EMI filter (common-mode and differential-mode).

inductance itself and this distributed interturn capacitance. Above the self-resonance point the capacitance becomes larger in value than the inductance, which then reduces the level of attenuation at high frequencies. The effect of this within the common-mode filter can be seen in Figure E–7. Its effect can be reduced by purposely using a larger X capacitor. The self-resonance frequency is the point in Figure E–7 at which the greatest possible attenuation for the filter is exhibited. By choosing the winding method of the transformer, one can locate this point on top of a frequency that needs the greatest filtering, such as a harmonic peak in the unfiltered system noise curve.

Another area of concern is the Q of the filter at self-resonance. If the Q is too high—in other words, if the damping factor is too low—the filter will actually generate noise in the form of narrow-band ringing. This can be dealt with during the design.

Some major transformer manufacturers build standard off-the-shelf components used in the design of common-mode filter transformers. such as Coilcraft. These transformers have various inductance values and current ratings, and also provide the needed creepage dimensions. This can make the designer's job a lot easier.

The initial common-mode filter component values can be determined in a step-by-step process (like everything else in this book). To begin this process, either a baseline measurement of the unfiltered conducted noise spectrum is needed, or some assumptions need to be made. in order to determine how much attenuation is needed and at what frequencies. Obviously, making the measurement will yield a good result (with minor tweaks) the first time. Assuming on paper that one needs a particular filter response may lead to additional "fudging" of the circuit on the test table.

A reasonable beginning is to assume that one needs about 24 dB of attenuation at the switching frequency of the switching power supply. This, of course, should be modified in response to the actual conducted noise spectral shape. One determines the corner frequency of the 2 pole filter from

$$\text{Attenuation}(-\text{dB}) = 40\log\left(\frac{f_c}{f_{sw}}\right)$$

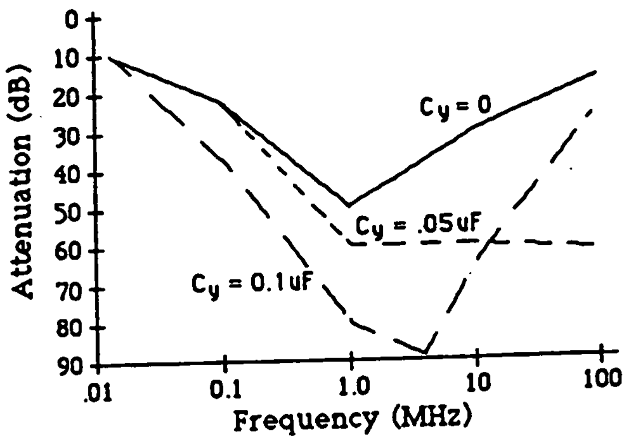


Figure E-7 Frequency response of a second-order common-mode filter (L = 1 mH).

or

$$f_c = f_{sw} \times 10^{(Att/40)}$$

where f_c is the desired corner frequency of the filter
f_{sw} is the operating frequency of the power supply

For this example, the switching frequency is assumed to be 50 kHz. The corner frequency to produce −24 dB of attenuation at this point is

$$f_c = (50\,\text{kHz}) \times 10^{(-24/40)} = 12.5\,\text{kHz}.$$

One assumes that the line impedance is 50 Ω (because that is the LISN test impedance). This impedance is then the damping element within the reactive filter circuit.

Choosing the damping factor

The minimum damping factor (ζ) should be no less than 0.707. Less than that would allow ringing to occur and produce less than 3 dB of attenuation at the corner frequency.

Calculating the initial component values

$$L = \frac{R_L \zeta}{\pi f_c} = \frac{(50\,\Omega)(0.707)}{\pi(12.5\,\text{kHz})} = 900\,\mu\text{H}.$$

$$C = \frac{1}{(2\pi f_c)^2 L} = \frac{1}{[2\pi(12.5\,\text{kHz})]^2(900\,\mu\text{H})} = 0.18\,\mu\text{F}.$$

Choosing "real-world" available components

The largest value of capacitor that is available in the 4 kV voltage rating is 0.05 μF. This is 27 percent of the calculated value. In order for the corner frequency to remain the same, the inductor value should be increased by a factor of 3.6. This would make the value 3.24 mH. The damping factor is directly proportional to the value of the inductance, so the resultant damping factor is 2.5, which is acceptable.

The closest Coilcraft common-mode inductor part number is E3493 and its self-resonance frequency is 1 MHz. The calculated capacitors are what are typically called "Y" capacitors. These are placed between each phase and the earth ground and must meet the full HIPOT test voltage of 2500 V_{rms}. "X" capacitors are placed between the power lines and need only meet the 250 V_{rms} rating of the power line and be able to withstand any surge that may be anticipated. Choosing the value of the X capacitors is mainly arbitrary and they usually fall in the 0.001–0.5 mF range.

One can reasonably expect this filter to provide a minimum of 60 dB of attenuation between the frequencies of 500 kHz and 10 MHz.

Once the component values have been calculated, the physical construction of the transformer and the PCB layout become critical for the effectiveness of the filter stage. Magnetic coupling due to stray inductive pick-up of high-frequency noise by the traces and components can circumvent the filter altogether; added to this is the fact that the common-mode filter choke looks more and more capacitive above its self-resonance frequency. The net result is that the designer needs to be concerned about the high frequency behavior of the filter typically above 20–40 MHz.

Physical layout of the PCB is important. The filter should be laid out in a linear fashion so that the input portion of the filter is physically distant from the output portion. Large, low-inductance traces should also be used, but keeping in mind the creepage requirements of the regulatory specifications.

Sometimes the high-frequency attenuation is insufficient to meet the specifications and a third pole has to be added to the EMI filter. This filter is typically a differential-mode filter and will share the Y capacitors from the common-mode filter. Its corner frequency is typically the same as that of the common-mode filter. This filter is made up of a separate choke on each power line, and is placed between the input rectifiers and the common-mode filter.

The differential-mode filter should have a lower damping factor than the common-mode filter because the combined damping response of the entire filter section would be too sluggish if higher damping factors were used. A minimum damping factor of 0.5 is acceptable.

Calculating the differential-mode choke value

$$L_d = \frac{R_L \zeta}{2\pi f_c} = \frac{(50\,\Omega)(0.5)}{2\pi(12.5\text{ kHz})} = 318\,\mu\text{H}.$$

The addition of this stage of filtering will bring the very high frequency attenuation under control and further attenuate any differential-mode noise on the earth ground lead. It will also produce a combined attenuation of −36 dB at the switching frequency of the power supply.

Real-world considerations

If one builds the inductive elements instead of buying off-the-shelf parts from a manufacturer, the following guidelines are common industry practices.

Common-mode chokes (transformers)

1. A toroid is best for this application because it produces very few stray magnetic fields.

2. A high permeability ferrite is used such as the W material from Magnetics, Inc. which has a permeability of 10 000.
3. If an E–E core is used (a common choice), there should be no air-gap and the mating surfaces of the cores must be polished. Any surface imperfections would lower the permeability.
4. The bobbin should be a two-section bobbin and should not be completely filled with windings. A 2 mm space from the outside surface of the bobbin is required for the 4 mm creepage requirement of VDE.

Differential-mode chokes

1. These are wound on separate cores (not mutually coupled).
2. Use a powdered iron material such as available from MicroMetals.
3. Bar cores are typically used because of cost.

EXHIBIT E

MOTOROLA

MC34261
MC33261

Power Factor Controllers

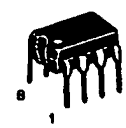
POWER FACTOR CONTROLLERS

SEMICONDUCTOR TECHNICAL DATA

The MC34261/MC33261 are active power factor controllers specifically designed for use as a preconverter in electronic ballast and in off–line power converter applications. These integrated circuits feature an internal startup timer, a one quadrant multiplier for near unity power factor, zero current detector to ensure critical conduction operation, high gain error amplifier, trimmed internal bandgap reference, current sensing comparator, and a totem pole output ideally suited for driving a power MOSFET.

Also included are protective features consisting of input undervoltage lockout with hysteresis, cycle–by–cycle current limiting, and a latch for single pulse metering. These devices are available in dual–in–line and surface mount plastic packages.

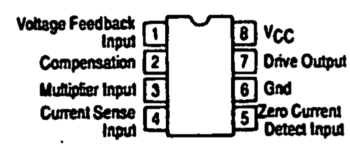
- Internal Startup Timer
- One Quadrant Multiplier
- Zero Current Detector
- Trimmed 2% Internal Bandgap Reference
- Totem Pole Output
- Undervoltage Lockout with Hysteresis
- Low Startup and Operating Current
- Pinout Equivalent to the SG3561
- Functional Equivalent to the TDA4817



P SUFFIX
PLASTIC PACKAGE
CASE 626

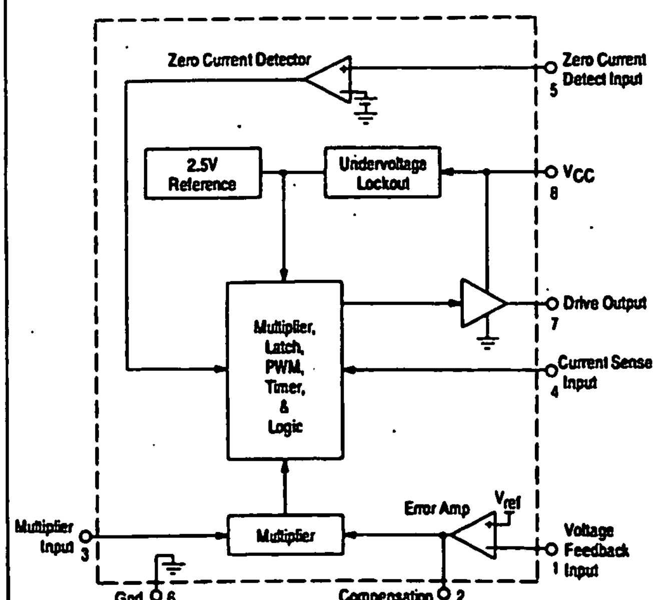
D SUFFIX
PLASTIC PACKAGE
CASE 751
(SO–8)

PIN CONNECTIONS



(Top View)

Simplified Block Diagram



ORDERING INFORMATION

Device	Operating Temperature Range	Package
MC34261D	T_A = 0° to +70°C	SO–8
MC34261P		Plastic DIP
MC33261D	T_A = –40° to +85°C	SO–8
MC33261P		Plastic DIP

Rev 1

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Total Power Supply and Zener Current	$(I_{CC} + I_Z)$	30	mA
Output Current, Source or Sink (Note 1)	I_O	500	mA
Current Sense, Multiplier, and Voltage Feedback Inputs	V_{in}	−1.0 to 10	V
Zero Current Detect Input High State Forward Current Low State Reverse Current	I_{in}	 50 −10	mA
Power Dissipation and Thermal Characteristics P Suffix, Plastic Package Case 626 Maximum Power Dissipation @ T_A = 70°C Thermal Resistance, Junction–to–Air D Suffix, Plastic Package Case 626 Maximum Power Dissipation @ T_A = 70°C Thermal Resistance, Junction–to–Air	 P_D $R_{\theta JA}$ P_D $R_{\theta JA}$	 800 100 450 178	 mW °C/W mW °C/W
Operating Junction Temperature	T_J	+150	°C
Operating Ambient Temperature (Note 3) MC34261 MC33261	T_A	 0 to +70 −40 to +85	°C
Storage Temperature	T_{stg}	−55 to +150	°C

ELECTRICAL CHARACTERISTICS (V_{CC} = 12 V, for typical values T_A = 25°C, for min/max values T_A is the operating ambient temperature range that applies [Note 3], unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
ERROR AMPLIFIER					
Voltage Feedback Input Threshold T_A = 25°C T_A = T_{low} to T_{high} (V_{CC} = 12 V to 28 V)	V_{FB}	 2.465 2.44	 2.5 	 2.535 2.54	V
Line Regulation (V_{CC} = 12 V to 28 V, T_A = 25°C)	Reg_{line}	–	1.0	10	mV
Input Bias Current (V_{FB} = 0 V)	I_{IB}	–	−0.3	−1.0	µA
Open Loop Voltage Gain	A_{VOL}	65	85	–	dB
Gain Bandwidth Product (T_A = 25°C)	GBW	0.7	1.0	–	MHz
Output Source Current (V_O = 4.0 V, V_{FB} = 2.3 V)	I_{Source}	0.25	0.5	0.75	mA
Output Voltage Swing High State (I_{Source} = 0.2 mA, V_{FB} = 2.3 V) Low State (I_{Sink} = 0.4 mA, V_{FB} = 2.7 V)	 V_{OH} V_{OL}	 5.0 –	 5.7 2.1	 – 2.44	V
MULTIPLIER					
Dynamic Input Voltage Range Multiplier Input (Pin 3) Compensation (Pin 2)	 $V_{Pin\ 3}$ $V_{Pin\ 2}$	 0 to 2.5 V_{FB} to (V_{FB} + 1.0)	 0 to 3.5 V_{FB} to (V_{FB} + 1.5)	 – –	V
Input Bias Current (V_{FB} = 0 V)	I_{IB}	–	−0.3	−1.0	µA
Multiplier Gain ($V_{Pin\ 3}$ = 0.5 V, $V_{Pin\ 2}$ = V_{FB} + 1.0 V) (Note 2)	K	0.4	0.62	0.8	1/V
ZERO CURRENT DETECTOR					
Input Threshold Voltage (V_{in} Increasing)	V_{th}	1.3	1.6	1.8	V
Hysteresis (V_{in} Decreasing)	V_H	40	110	200	mV
Input Clamp Voltage High State (I_{DET} = 3.0 mA) Low State (I_{DET} = −3.0 mA)	 V_{IH} V_{IL}	 6.1 0.3	 6.7 0.7	 – 1.0	V

NOTES: 1. Maximum package power dissipation limits must be observed.

2. $K = \dfrac{\text{Pin 4 Threshold Voltage}}{V_{Pin\ 3}(V_{Pin\ 2} - V_{FB})}$

3. T_{low} = 0°C for MC34261 = −40°C for MC33261 T_{high} = +70°C for MC34261 = +85°C for MC33261

ELECTRICAL CHARACTERISTICS (V_{CC} = 12 V, for typical values T_A = 25°C, for min/max values T_A is the operating ambient temperature range that applies [Note 3], unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
CURRENT SENSE COMPARATOR					
Input Bias Current ($V_{Pin\ 4}$ = 0 V)	I_{IB}	–	–0.5	–2.0	µA
Input Offset Voltage ($V_{Pin\ 2}$ = 1.1 V, $V_{Pin\ 3}$ = 0 V)	V_{IO}	–	3.5	15	mV
Delay to Output	$t_{PHL(in/out)}$	–	200	400	ns
DRIVE OUTPUT					
Output Voltage (V_{CC} = 12 V)					V
Low State (I_{Sink} = 20 mA)	V_{OL}	–	0.3	0.8	
(I_{Sink} = 200 mA)		1.8	2.4	3.3	
High State (I_{Source} = 20 mA)	V_{OH}	9.8	10.3	–	
(I_{Source} = 200 mA)		7.8	8.3	8.8	
Output Voltage (V_{CC} = 30 V) High State (I_{Source} = 20 mA, C_L = 15 pF)	$V_{O(max)}$	14	16	18	V
Output Voltage Rise Time (C_L = 1.0 nF)	t_r	–	50	120	ns
Output Voltage Fall Time (C_L = 1.0 nF)	t_f	–	50	120	ns
Output Voltage with UVLO Activated (V_{CC} = 7.0 V, I_{Sink} = 1.0 mA)	$V_{OH(UVLO)}$	–	0.2	0.8	V
RESTART TIMER					
Restart Time Delay	t_{DLY}	150	400	–	µs
UNDERVOLTAGE LOCKOUT					
Startup Threshold (V_{CC} Increasing)	V_{th}	9.2	10.0	10.8	V
Minimum Operating Voltage After Turn–On (V_{CC} Decreasing)	$V_{Shutdown}$	7.0	8.0	9.0	V
Hysteresis	V_H	1.75	2.0	2.5	V
TOTAL DEVICE					
Power Supply Current	I_{CC}				mA
Startup (V_{CC} = 7.0 V)		–	0.3	0.5	
Operating		–	7.1	12	
Dynamic Operating (50 kHz, C_L = 1.0 nF)		–	9.0	20	
Power Supply Zener Voltage	V_Z	30	36	–	V

NOTES: 1. Maximum package power dissipation limits must be observed.

2. $K = \dfrac{\text{Pin 4 Threshold Voltage}}{V_{Pin\ 3}(V_{Pin\ 2} - V_{FB})}$

3. T_{low} = 0°C for MC34261, = –40°C for MC33261; T_{high} = +70°C for MC34261, = +85°C for MC33261

Figure 1. Current Sense Input Threshold versus Multiplier Input

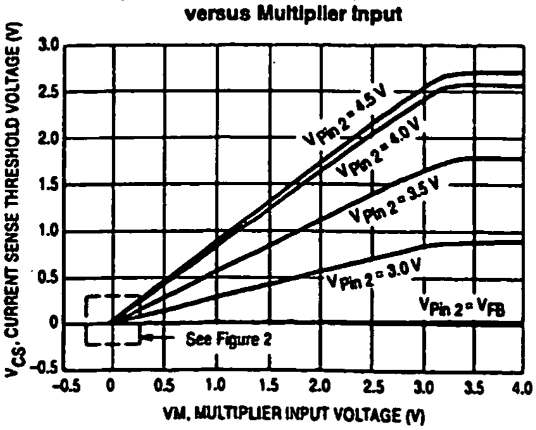


Figure 2. Current Sense Input Threshold versus Multiplier Input

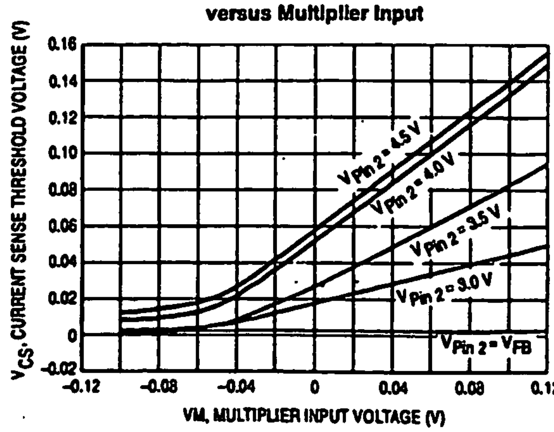


Figure 3. Voltage Feedback Input Threshold Change versus Temperature

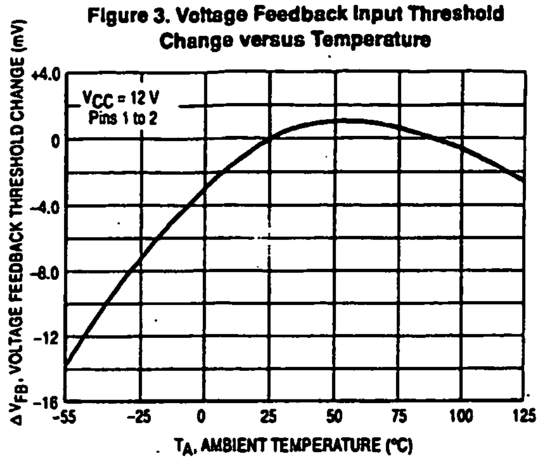


Figure 4. Error Amp Open Loop Gain and Phase versus Frequency

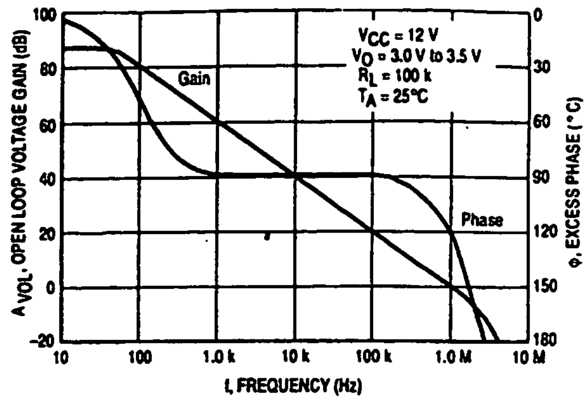


Figure 5. Error Amp Small Signal Transient Response

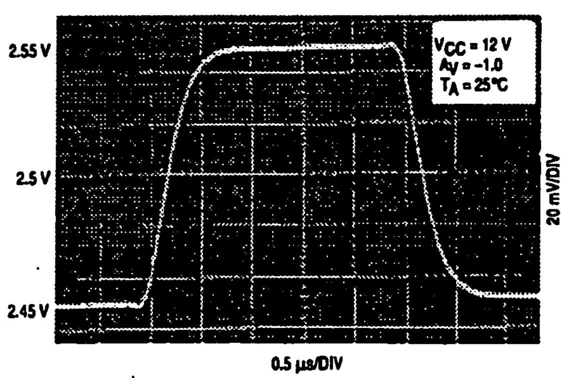


Figure 6. Error Amp Large Signal Transient Response

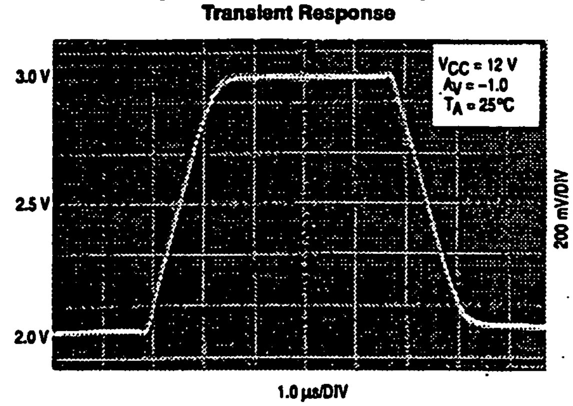


Figure 7. Error Amp Output Saturation versus Sink Current

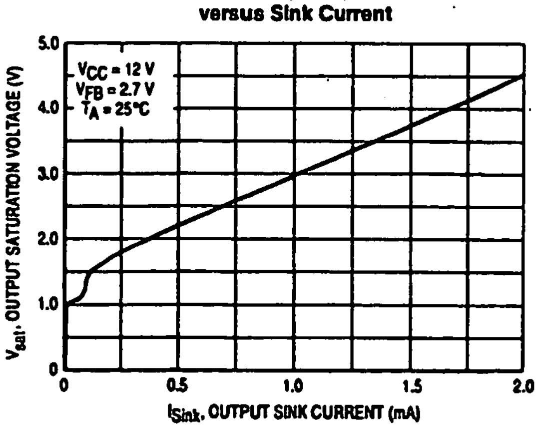


Figure 8. Restart Time Delay versus Temperature

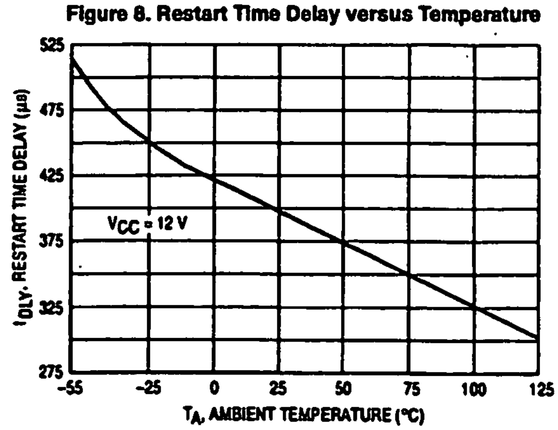
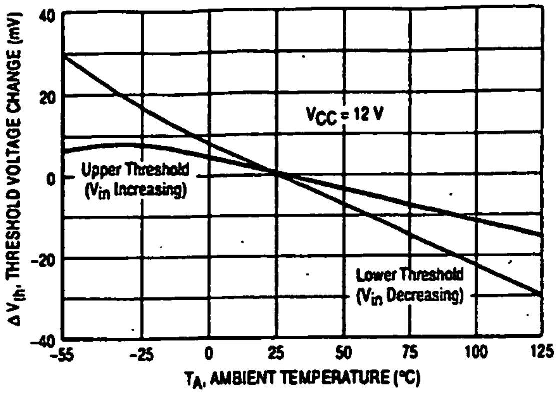


Figure 9. Zero Current Detector Input Threshold Voltage Change versus Temperature



Figur 10. Output Saturati n Voltage versus Load Current

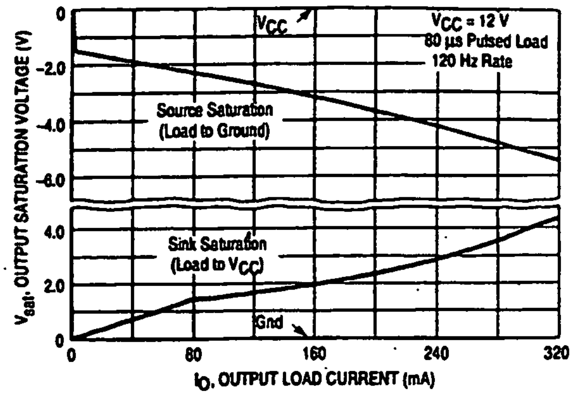


Figure 11. Drive Output Waveform

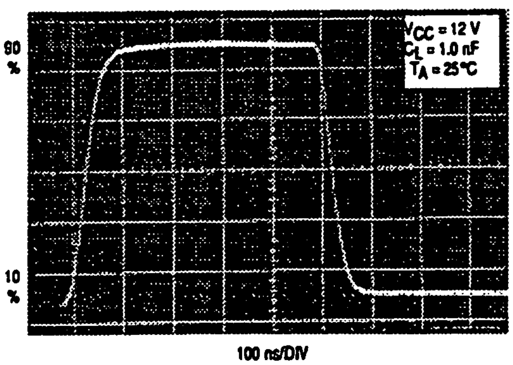


Figure 12. Drive Output Cross Conduction

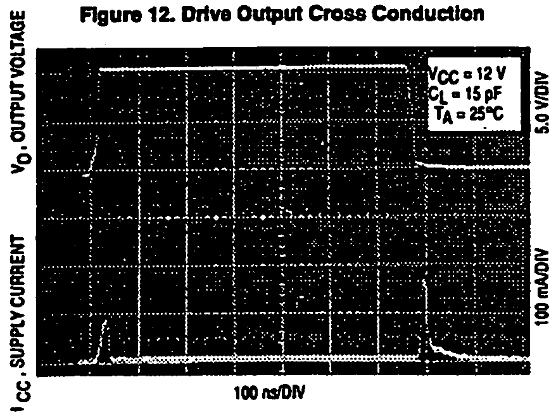


Figure 13. Supply Current versus Supply Voltage

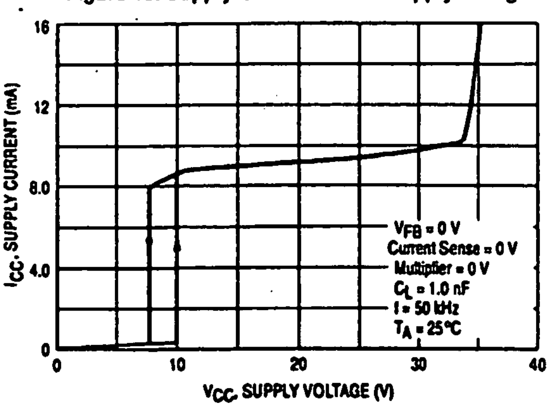
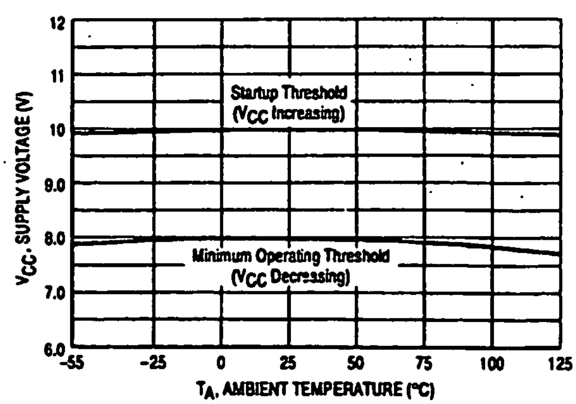


Figure 14. Undervoltage Lockout Thresholds versus Temperature



FUNCTIONAL DESCRIPTION

Introduction

Most electronic ballasts and switching power supplies use a bridge rectifier and a filter capacitor to derive raw dc voltage from the utility ac line. This simple rectifying circuit draws power from the line when the instantaneous ac voltage exceeds the capacitor's voltage. This occurs near the line voltage peak and results in a high charge current spike. Since power is only taken near the line voltage peaks, the resulting spikes of current are extremely nonsinusoidal with a high content of harmonics. This results in a poor power factor condition where the apparent input power is much higher than the real power.

The MC34261, MC33261 are high performance, critical conduction, current mode power factor controllers specifically designed for use in off–line active preconverters. These devices provide the necessary features required to significantly enhance poor power factor loads by keeping the ac line current sinusoidal and in phase with the line voltage. With proper control of the preconverter, almost any complex load can be made to appear resistive to the ac line, thus significantly reducing the harmonic current content.

Operating Description

The MC34261, MC33261 contains many of the building blocks and protection features that are employed in modern high performance current mode power supply controllers. There are, however, two areas where there is a major difference when compared to popular devices such as the UC3842 series. Referring to the block diagram in Figure 15, note that a multiplier has been added to the current sense loop and that this device does not contain an oscillator. A description of each of the functional blocks is given below.

Error Amplifier

A fully compensated Error Amplifier with access to the inverting input and output is provided. It features a typical dc voltage gain of 85 dB, and a unity gain bandwidth of 1.0 MHz with 58° of phase margin (Figure 4). The noninverting input is internally biased at 2.5 V ±2.0% and is not pinned out. The output voltage of the power factor converter is typically divided down and monitored by the inverting input. The maximum input bias current is −1.0 µA which can cause an output voltage error that is equal to the product of the input bias current and the value of the upper divider resistor R_2. The Error Amp Output is internally connected to the Multiplier and is pinned out (Pin 2) for external loop compensation. Typically, the bandwidth is set below 20 Hz, so that the Error Amp output voltage is relatively constant over a given ac line cycle. The output stage consists of a 500 µA current source pull–up with a Darlington transistor pull–down. It is capable of swinging from 2.1 V to 5.7 V, assuring that the Multiplier can be driven over its entire dynamic range.

Multiplier

A single quadrant, two input multiplier is the critical element that enables this device to control power factor. The ac haversines are monitored at Pin 3 with r spect to ground while the Error Amp output at Pin 2 is monitored with respect to the Voltage Feedback Input threshold. A graph of the Multiplier transfer curve is shown in Figure 1. Note that both inputs are extremely linear over a wide dynamic range, 0 V to 3.2 V for the Multiplier input (Pin 3), and 2.5 V to 4.0 V for the Error Amp output (Pin 2). The Multiplier output controls the Current Sense Comparator threshold (Pin 4) as the ac voltage traverses sinusoidally from zero to peak line. This has the effect of forcing the MOSFET peak current to track the input line voltage, thus making the preconverter load appear to be resistive.

$$\text{Pin 4 Threshold} \approx 0.62(V_{\text{Pin 2}} - V_{FB})V_{\text{Pin 3}}$$

Zero Current Detector

The MC34261 operates as a critical conduction current mode controller, whereby output switch conduction is initiated by the Zero Current Detector and terminated when the peak inductor current reaches the threshold level established by the Multiplier output. The Zero Current Detector initiates the next on–time by setting the RS Latch at the instant the inductor current reaches zero. This critical conduction mode of operation has two significant benefits. First, since the MOSFET cannot turn on until the inductor current reaches zero, the output rectifier's reverse recovery time becomes less critical allowing the use of an inexpensive rectifier. Second, since there are no deadtime gaps between cycles, the ac line current is continuous thus limiting the peak switch to twice the average input current.

The Zero Current Detector indirectly senses the inductor current by monitoring when the auxiliary winding voltage falls below 1.6 V. To prevent false tripping, 110 mV of hysteresis is provided. The Zero Current Detector input is internally protected by two clamps. The upper 6.7 V clamp prevents input overvoltage breakdown while the lower 0.7 V clamp prevents substrate injection. Device destruction can result if this input is shorted to ground. An external resistor must be used in series with the auxiliary winding to limit the current through the clamps.

Current Sense Comparator and RS Latch

The Current Sense Comparator RS Latch configuration ensures that only a single pulse appears at the Drive Output during a given cycle. The inductor current is converted to a voltage by inserting a ground referenced sense resistor R_9 in series with the source of output switch Q1. This voltage is monitored by the Current Sense Input and compared to the Multiplier output voltage. The peak inductor current is controlled by the threshold voltage of Pin 4 where:

$$I_{pk} = \frac{\text{Pin 4 Threshold}}{R_9}$$

With the component values shown in Figure 16, the Current Sense Comparator threshold, at the peak of the haversine varies from 1.1 V at 90 Vac to 100 mV at 268 Vac. The Current Sense Input to Drive Output propagation delay is typically 200 ns.

Timer

A watchdog timer function was added to the IC to eliminate the need for an external oscillator when used in stand alone applications. The Timer provides a means to automatically start or restart the preconverter if the Drive Output has been off for more than 400 µs after the inductor current reaches zero.

Undervoltage Lockout

An Undervoltage Lockout comparator guarantees that the IC is fully functional before enabling the output stage. The positive power supply terminal (V_{CC}) is monitored by the UVLO comparator with the upper threshold set at 10 V and the lower threshold at 8.0 V (Figure 14). In the standby mode, with V_{CC} at 7.0 V, the required supply current is less than 0.5 mA (Figure 13). This hysteresis and low startup current allow the implementation of efficient bootstrap startup techniques, making these devices ideally suited for wide input range off line preconverter applications. An internal 36 V clamp has been added from V_{CC} to ground to protect the IC and capacitor C_5 from an overvoltage condition. This feature is desirable if external circuitry is used to delay the startup of the preconverter.

Output

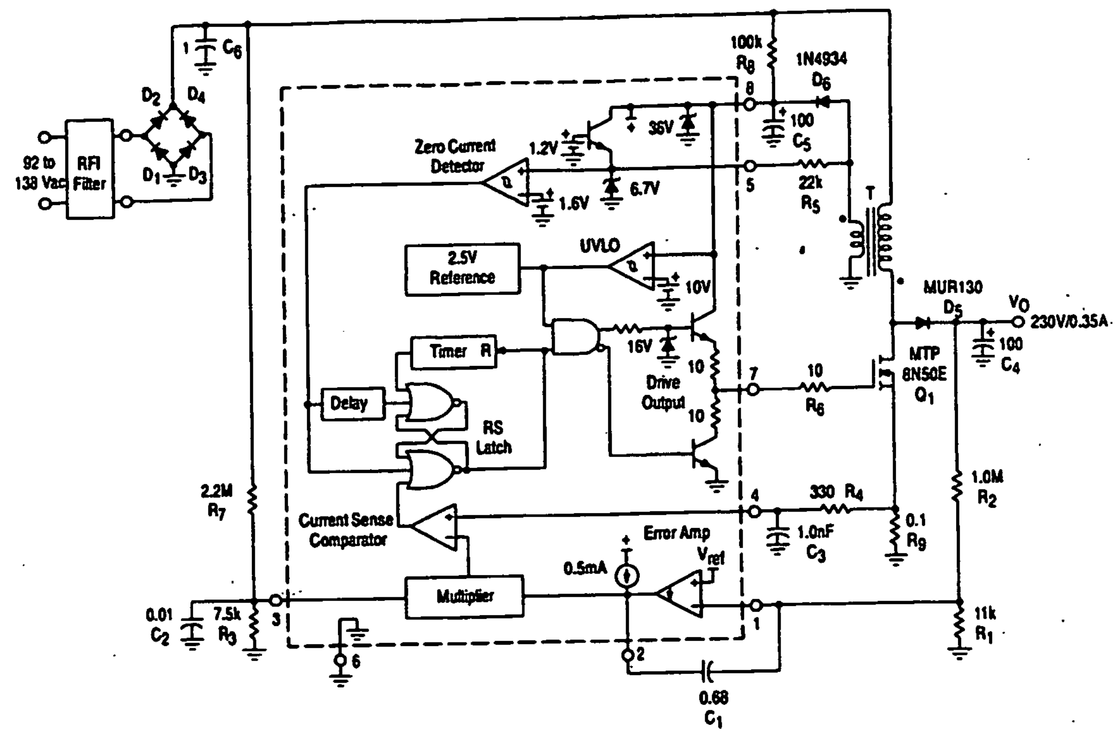
The MC34261/MC33261 contain a single totem pole output stage specifically designed for direct drive of power MOSFETs. The Drive Output is capable of up to ±500 mA peak current with a typical rise and fall time of 50 ns with a 1.0 nF load. Additional internal circuitry has been added to keep the Drive Output in a sinking mode whenever the Undervoltage Lockout is active. This characteristic eliminates the need for an external gate pull–down resistor. The totem pole output has been optimized to minimize cross conduction current during high speed operation. The addition of two 10 Ω resistors, one in series with the source output transistor and one in series with the sink output transistor, reduces the cross conduction current, as shown in Figure 12. A 16 V clamp has been incorporated into the output stage to limit the high state V_{OH}. This prevents rupture of the MOSFET gate when V_{CC} exceeds 20 V.

Table 1. Design Equations

Notes	Calculation	Formula
Calculate the maximum required output power.	Required Converter Output Power	$P_O = V_O I_O$
Calculated at the minimum required ac line for regulation. Let the efficiency η = 0.95.	Peak Inductor Current	$I_{L(pk)} = \dfrac{2\sqrt{2}P_O}{\eta Vac_{(LL)}}$
Let the switching cycle t = 20 µs.	Inductance	$L = \dfrac{2t\left(\frac{V_O}{\sqrt{2}} - Vac\right)Vac^2}{V_O\,Vac_{(LL)}\,I_{L(pk)}}$
In theory the on–time t_{on} is constant. In practice t_{on} tends to increase at the ac line zero crossings due to the charge on capacitor C_6.	Switch On–Time	$t_{on} = \dfrac{2P_O L}{\eta\,Vac^2}$
The off–time t_{off} is greatest at peak ac line and approaches zero at the ac line zero crossings. Theta (θ) represents the angle of the ac line voltage.	Switch Off–Time	$t_{off} = \dfrac{t_{on}}{\dfrac{V_O}{\sqrt{2}\,Vac\,\lvert \sin\theta\rvert} - 1}$
The minimum switching frequency occurs at peak ac line and increases as t_{off} decreases.	Switching Frequency	$f = \dfrac{1}{t_{on} + t_{off}}$
Set the current sense threshold V_{CS} to 1.0 V for universal input (85 Vac to 265 Vac) operation and to 0.5 V for fixed input (92 Vac to 138 Vac, or 184 to 276 Vac) operation.	Peak Switch Current	$R_9 = \dfrac{V_{CS}}{I_{L(pk)}}$
Set the multiplier input voltage V_M to 3.0 V at high line. Empirically adjust V_M for the lowest distortion over the ac line range while guaranteeing startup at minimum line.	Multiplier Input Voltage	$V_M = \dfrac{Vac\sqrt{2}}{\left(\frac{R_7}{R_3} + 1\right)}$
The $I_{IB}R_1$ error term can be minimized with a divider current in excess of 100 µA.	Converter Output Voltage	$V_O = V_{ref}\left(\frac{R_2}{R_1} + 1\right) - I_{IB}R_2$
The bandwidth is typically set to 20 Hz for minimum output ripple over the ac line haversine.	Error Amplifier Bandwidth	$BW = \dfrac{1}{2\pi\frac{R_1R_2}{R_1 + R_2}C_1}$

The following converter characteristics must be chosen:
V_O – Desired output voltage   Vac – AC RMS line voltage
I_O – Desired output current $Vac_{(LL)}$ – AC RMS low line voltage

Figure 15. 80 W Power Factor Controller



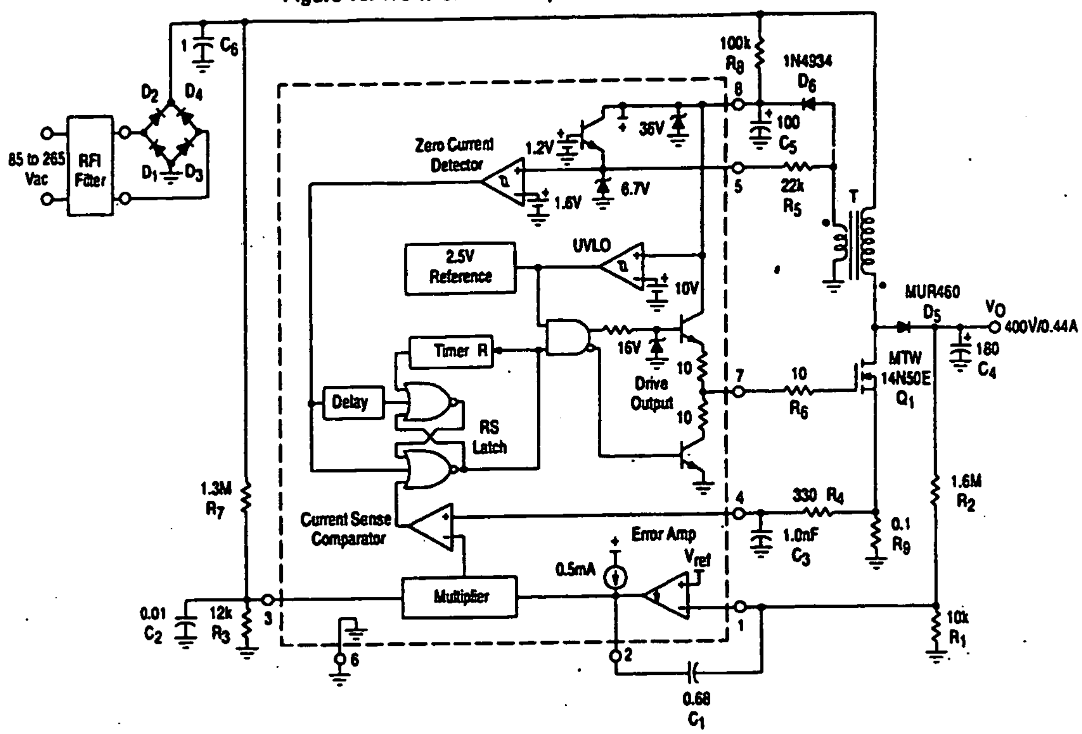
Power Factor Controller Test Data

AC Line Input								DC Output				
			Current Harmonic Distortion (%)									
V_{rms}	P_{in}	PF	THD	2	3	5	7	$V_{O(pp)}$	V_O	I_O	P_O	n(%)
90	85.6	–0.998	2.4	0.11	0.52	1.3	0.67	10.0	230	0.350	80.5	94.0
100	85.1	–0.997	5.0	0.13	1.7	2.4	1.4	10.1	230	0.350	80.5	94.6
110	84.8	–0.997	5.3	0.12	2.5	2.6	1.5	10.2	230	0.350	80.5	94.9
120	84.5	–0.997	5.8	0.12	3.2	2.7	1.4	10.2	230	0.350	80.5	95.3
130	84.2	–0.996	6.6	0.12	4.0	2.8	1.5	10.2	230	0.350	80.5	85.6
138	84.1	–0.995	7.2	0.13	4.5	3.0	1.6	10.2	230	0.350	80.5	95.7

This data was taken with the test set–up shown in Figure 17.

T = Coilcraft N2881–A
Primary: 62 turns of # 22 AWG
Secondary: 5 turns of # 22 AWG
Core: Coilcraft PT2510, EE 25
Gap: 0.072" total for a primary inductance of 320 µH
Heatsink = AAVID Engineering Inc. 5903B, or 5930B

Figure 16. 175 W Universal Input Power Factor Controller



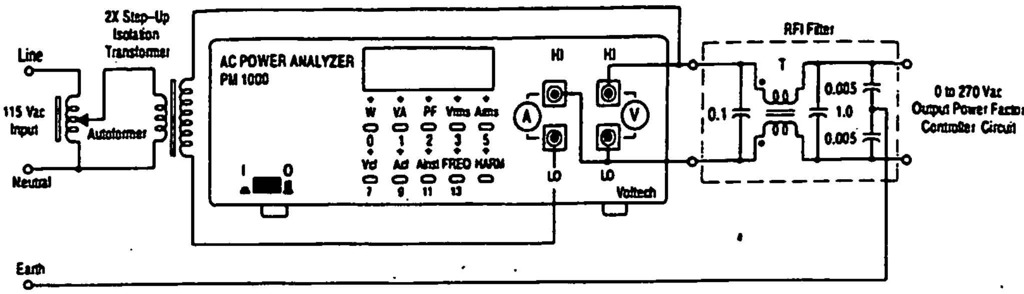
Power Factor Controller Test Data

AC Line Input								DC Output				
			Current Harmonic Distortion (%)									
V_{rms}	P_{in}	PF	THD	2	3	5	7	$V_{O(pp)}$	V_O	I_O	P_O	n(%)
90	187.5	−0.998	2.0	0.10	0.98	0.90	0.78	8.0	400.7	0.436	174.7	93.2
120	184.6	−0.997	1.8	0.09	1.3	1.3	0.93	8.0	400.7	0.436	174.7	94.6
138	183.6	−0.997	2.3	0.05	1.6	1.5	1.0	8.0	400.7	0.436	174.7	95.2
180	181.0	−0.995	4.3	0.16	2.5	2.0	1.2	8.0	400.6	0.436	174.7	95.6
240	179.3	−0.993	6.0	0.08	3.7	2.7	1.4	8.0	400.6	0.436	174.7	97.4
268	178.6	−0.992	6.7	0.16	2.8	3.7	1.7	8.0	400.6	0.436	174.7	97.8

This data was taken with the test set–up shown in Figure 17.

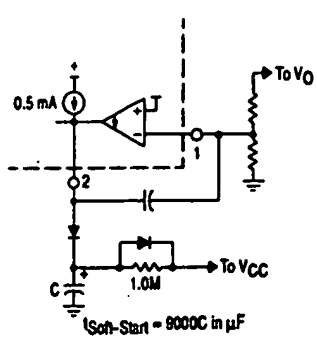
T = Coilcraft N2880–A
Primary: 78 turns of # 16 AWG
Secondary: 6 turns of # 18 AWG
Core: Coilcraft PT4215, EE 42–15
Gap: 0.104" total for a primary inductance of 870 µH
Heatsink = AAVID Engineering Inc. 5903B

Figur 17. P wer Fact r T st Set–Up



An RFI filter is required for best performance when connecting the preconverter directly to the AC line. Commercially available two stage filters such as the Delta Electronics 03DPCG5 work excellent. The simple single stage test filter shown above can easily be constructed with a common mode transformer. Transformer (T) is a Coilcraft CMT3–28–2 with 28 mH minimum inductance and a 2.0 A maximum current rating.

Figure 18. Soft–Start Circuit



$t_{Soft-Start} = 9000C$ in μF

Startup overshoot can be eliminated with the addition of a Soft–Start circuit.

Figure 19. Error Amp Compensation

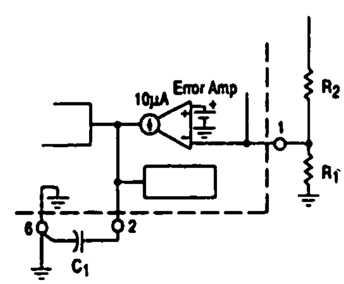
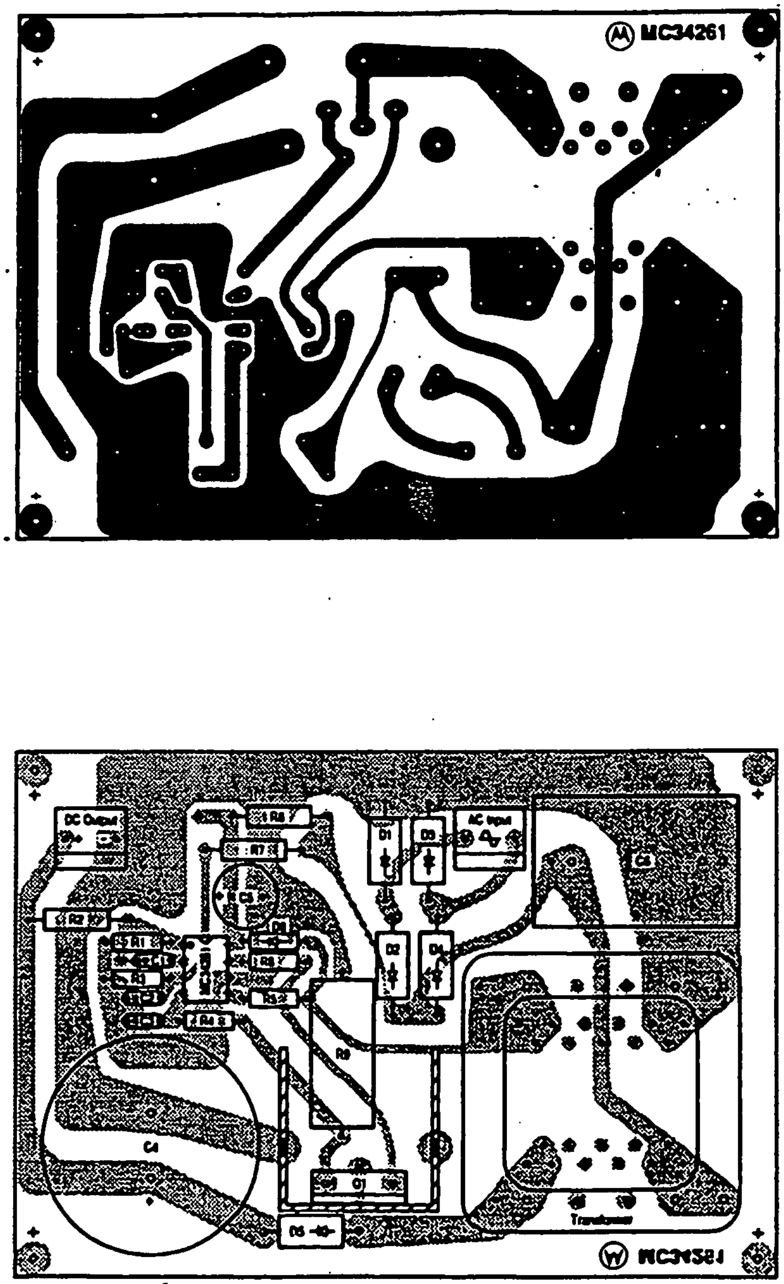
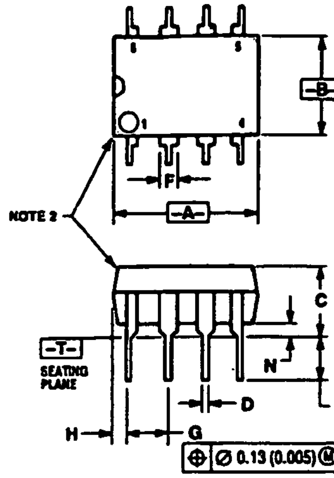


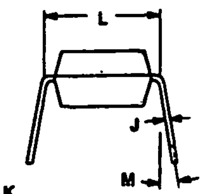
Figure 20. Printed Circuit Board and Component Layout
(Circuits of Figures 15 and 16)



OUTLINE DIMENSIONS

P SUFFIX
PLASTIC PACKAGE
CASE 626–05
ISSUE K

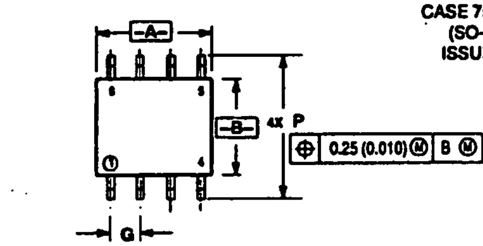


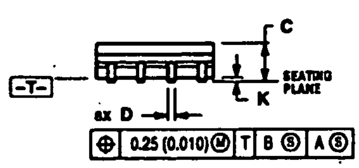


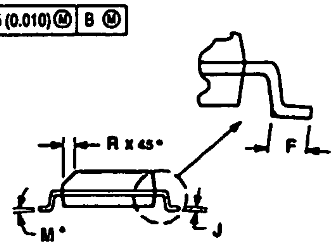
NOTES:
1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	10.16	0.370	0.400
B	6.10	6.60	0.240	0.260
C	3.94	4.45	0.155	0.175
D	0.38	0.51	0.015	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
H	0.76	1.27	0.030	0.050
J	0.20	0.30	0.008	0.012
K	2.92	3.43	0.115	0.135
L	7.62 BSC		0.300 BSC	
M	—	10°	—	10°
N	0.76	1.01	0.030	0.040

D SUFFIX
PLASTIC PACKAGE
CASE 751–05
(SO–8)
ISSUE N







NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	4.80	5.00	0.189	0.196
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.054	0.068
D	0.35	0.49	0.014	0.019
F	0.40	1.25	0.016	0.049
G	1.27 BSC		0.050 BSC	
J	0.18	0.25	0.007	0.009
K	0.10	0.25	0.004	0.009
M	0°	7°	0°	7°
P	5.80	6.20	0.229	0.244
R	0.25	0.50	0.010	0.019

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JAPAN: Nippon Motorola Ltd.; SPD, Strategic Planning Office, 4–32–1,
Nishi–Gotanda, Shinagawa–ku, Tokyo 141, Japan. 81–3–5487–8488

Mfax™: RMFAX0@email.sps.mot.com – TOUCHTONE 602–244–6609
– US & Canada ONLY 1–800–774–1848

ASIA/PACIFIC: Motorola Semiconductors H.K. Ltd.; 8B Tai Ping Industrial Park,
51 Ting Kok Road, Tai Po, N.T., Hong Kong. 852–26629298

INTERNET: http://motorola.com/sps

EXHIBIT F

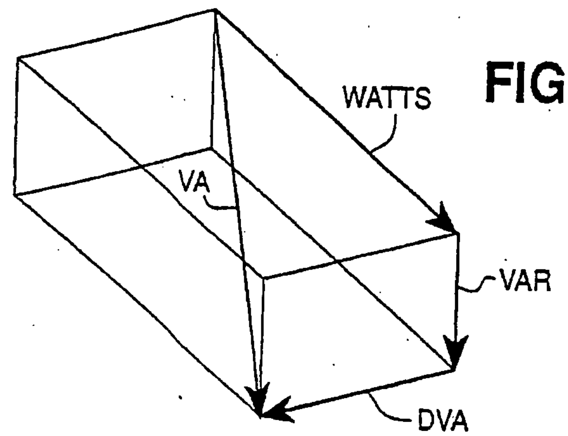


FIG - 4

FIG - 6a

Amended

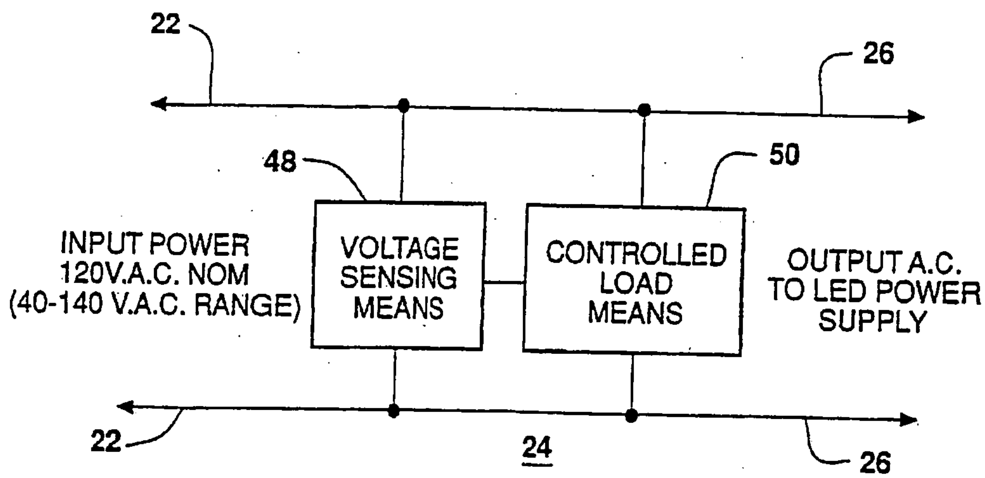


FIG - 6b

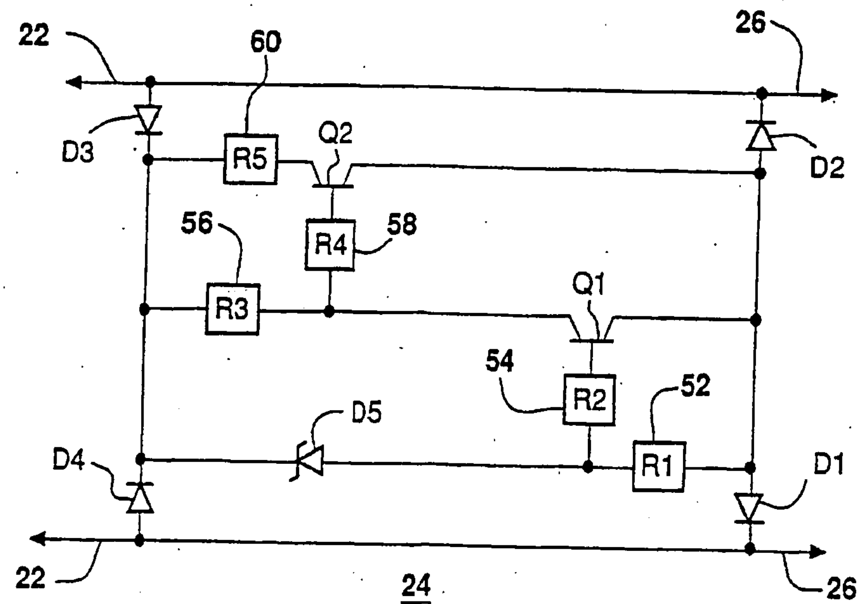


EXHIBIT G

with

Exhibit A
Exhibit B
Exhibit C

Attorney Docket No. 9100.2881 REI

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Peter A. Hochstein	)	
Application No.:	09/382,702	)	TC Art Unit: 2838
Reissue Filed:	August 24, 1999	)	Examiner: B. Vu
Original Patent: Issued:	5,661,645 August 26, 1997	)	
For: POWER SUPPLY FOR LIGHT EMITTING DIODE ARRAY		)	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION OF PETER A. HOCHSTEIN

I, Peter A. Hochstein, hereby declare as follows:

1. I am the named inventor on the above-identified application, which was filed to reissue my U.S. Patent 5,661,645 ("the original '645 patent"). I am therefore familiar with the technical disclosure of the present application and the original '645 patent; citations herein to the disclosure are to the patent. I have also read numerous references that have been used from time to time in rejections of claims presented in the above-identified application, including U.S. Patent 5,075,601 to Hildebrand, U.S. Patent No. 5,463,280 to Johnson, Brown, M., Power Supply Cookbook, 1994, pp. 25, 26, 72, 73, and 195-225 (Motorola Series in Solid State Electronics; Butterworth-Heineman), and the Motorola data sheet for the MC 34261 controller.

2. I am the same Peter Hochstein who submitted the Declaration of Peter Hochstein, dated December 1, 1998, in *Relume Corp. v. Dialight Corporation et al.*, Case No. 98-CV-

72360, the U.S. District Court final decision reported at 63 F.Supp.2d 788 (E.D. Mich. 1999) ("the previous Hochstein Declaration").

Specification Description of Embodiments of Claimed Invention

3. I am informed that claim 24 as set out below is being submitted in a Preliminary Amendment in the above-identified application concurrently with this Declaration:

> Claim 24. A power supply assembly for powering light emitting diodes (LEDs) in an outdoor line-connected signal, comprising:
>
> an electrical input for coupling to a source of a.c. line voltage through a solid state traffic controller switch for providing an electrical input voltage having an operating range when the switch is on;
>
> a rectifier coupled to the electrical input and having a rectifier output;
>
> a line voltage regulating switchmode power supply having a power supply input coupled to the rectifier output and a power supply output;
>
> a plurality of LEDs coupled to the power supply output and having multiple current paths for emitting light in response to the power supply output; and
>
> a conflict monitor compatibility circuit including a low impedance load and a transistor in series connection with the low impedance load, the transistor being biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is within the operating range and an essentially conductive condition if the electrical input voltage drops below a predetermined value lower than the operating range, wherein the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.

4. I have compared this claim to the disclosure of the above-identified application, and I find that the disclosure describes an embodiment of a power supply assembly having all of the features recited in claim 24. The following chart explains in detail where in the application describes an embodiment of each of the features in claim 24.

Claim 24	Disclosed Embodiment
A power supply assembly for powering light emitting diodes (LEDs) in an outdoor line-connected signal, comprising:	A power supply assembly 10 connected to an a.c. line voltage powers a light emitting diode array signal 12. Col. 5, lines 11-13; Fig. 5.

an electrical input for coupling to a source of a.c. line voltage through a solid state traffic controller switch for providing an electrical input voltage having an operating range when the switch is on;	The assembly 10 includes an electrical input 22 coupled to the a.c. power line through a solid state switch that provides operating voltages from 85 to 140 volts (a nominal 120 volt a.c. line). Col. 5, lines 15-18, col. 6, lines 27-30; Figs. 5, 6a, 6b.
a rectifier coupled to the electrical input and having a rectifier output;	A full wave rectifier 32 is coupled by lines 30 to the electrical input 22 and has an output 34. Col. 5, lines 35-39; Fig. 5.
a line voltage regulating switchmode power supply having a power supply input coupled to the rectifier output and a power supply output;	A line voltage regulating switchmode power supply 38 has an input coupled to the rectifier output 34 and an output 42,44. Col. 5, lines 41-54; Fig. 5.
a plurality of LEDs coupled to the power supply output and having multiple current paths for emitting light in response to the power supply output; and	A plurality of LEDs 16 coupled to the power supply output 42,44 have multiple current paths and emit light in response to the power supply output. Col. 5, lines 5-10, col. 6, lines 24-27; Fig. 5.
a conflict monitor compatibility circuit including a low impedance load and a transistor in series connection with the low impedance load,	A circuit 24 includes a low impedance resistor 60 connected in series with a transistor Q2. The circuit 24 "eliminates problems with conflict monitors." Col. 6, lines 57-62, col. 7, lines 12-15, 46-50; Figs. 5, 6a, 6b.
the transistor being biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is within the operating range and	The bipolar transistor switch Q2 is off ("essentially nonconductive") whenever the traffic controller switch is on to provide the nominal 120 volts (with a range of 85-140 volts) at the electrical input 22 so that a Zener diode D5 reverse-conducts from cathode to anode. Col. 7, lines 45, 63-67; Fig. 6b.
an essentially conductive condition if the electrical input voltage drops below a predetermined value lower than the operating range,	The transistor Q2 is on ("essentially conductive") if the electrical input 22 drops below 40 volts (lower than the 85-140 volt operating range) and prevents the Zener diode D5 from conducting in the reverse direction. Col. 7, lines 53-60; Fig. 6b.
wherein the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.	"If the Zener diode D5 does not conduct, the transistor Q2 is turned on to place the load resistor 60 [in] the power lines 22 causing the leakage voltage [from the solid state switch] to drop below 10 volts." Col. 7, lines 18-30, 59-62; Fig. 6b.

5. I am informed that the Preliminary Amendment also presents claims 28 and 32 similar to claim 24, except that the "line voltage regulating switchmode power supply" of claim 24 is replaced in claim 28 by "a switchmode power supply for maintaining current and voltage waveforms substantially in phase and for providing a regulated current output with respect to variations in the input line voltage," and is replaced in claim 32 by "a switchmode power supply for improving poor power factor, whereby the power supply provides essentially constant current at a power supply output with respect to variations in line voltage input, and whereby current and voltage waveforms are maintained substantially in phase." Embodiments of these power supplies, which are conventional, are generally described at column 5, lines 42-57, of the original '645 patent.

6. I am informed that the Preliminary Amendment also presents the following claim 44 in the above-identified application:

> Claim 44. A conflict monitor compatibility circuit for use in traffic and pedestrian signaling applications, comprising:
>
> a plurality of LEDs for emitting light in response to an electrical input adapted to be coupled to a source of a.c. line voltage through a solid state traffic controller switch for providing an electrical input voltage having an operating range when the switch is on;
>
> a transistor biased as a switch that has an essentially nonconductive condition whenever the electrical input voltage is within the operating range and an essentially conductive condition if the electrical input voltage drops below a predetermined value lower than the operating range; and
>
> a low impedance load in series connection with the transistor, wherein the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.

It will be readily apparent from the above discussion of claim 24 that the present application contains a description of an embodiment of the circuit recited in claim 44.

7. I am informed that the Preliminary Amendment also presents dependent claims with the following features.

> Claim 46. The assembly according to claim 24, 28, or 32, wherein the conflict monitor compatibility circuit further includes a sensor for providing a control output if the electrical input voltage drops below the predetermined value and a control element for switching the transistor to the essentially conductive condition in response to the control output.
>
> Claim 47 The assembly according to claim 46, wherein the sensor is a Zener diode that conducts in a reverse direction only at voltages above the predetermined value.
>
> Claim 48. The assembly according to claim 47, wherein the control element is a second transistor biased as a switch and having a base coupled to the Zener diode.

8. The chart in paragraph 4 above discusses the Zener diode D5, which in claims 47 and 48 provides an embodiment of a sensor that switches the transistor Q2 on and off at the same predetermined voltage. The control element in the disclosed embodiment is the npn bipolar transistor Q1 that switches the first transistor Q2 on and off when the transistor Q1 is off and on, respectively. Col. 5, lines 4-10, 57-67; Figs. 6a, 6b. I am informed that the Preliminary Amendment also presents dependent claims 51-53 similar to claims 46-48, respectively, but dependent from claim 44. Accordingly, claims 51-53 also recite structure that is described in the context of a preferred embodiment in the disclosure of the present application.

9. It is my understanding that pointing out where the specification describes preferred embodiments of claim features does not limit the claims to those embodiments. Accordingly, the above discussion should not be taken as an indication that I believe that the claims are so limited. In addition, it should be clear that the phrase "coupled to" used in the claims does not require a direct connection between the "coupled" circuit elements. Rather, it refers to the operative interconnection between the elements that enables the claimed structure to operate as claimed.

10. I have noted that Fig. 6a should include a functional connection between the voltage sensing means 48 and the controlled load means 50, as represented in Fig. 6b by the circuit line including the resistor 58. See col. 7, lines 57-59. Accordingly, there should be a line between these two "means" in Fig. 6a to make the drawings consistent with the description in the specification.

Differences Between Claims and U.S. Patent 5,075,601 to Hildebrand

11. This discussion focuses on U.S. Patent 5,075,601 to Hildebrand ("Hildebrand") and the differences between it and the conflict monitor compatibility circuits in independent claims 24, 28, 32, and 44. That should not be taken as an opinion on my part one way or the other as to the relevance to those claims of the other references mentioned in paragraph 1. I will use the conflict monitor compatibility circuit recited in claim 24 as representative of the similarly recited structure in independent claims 28, 32, and 44. That is, any differences among claims 24, 28, 32, and 44 are not specifically relevant to the differences between the claimed invention and Hildebrand.

12. The claimed conflict monitor compatibility circuit is an important feature of power supply assemblies with signals that are lit by LEDs controlled by a solid-state traffic controller switch (as recited in claims 24, 28, 32, and 44) rather than by the long-conventional incandescent lamps. Prior art signals include a conflict monitor circuit as a safety feature. This circuit senses if signals being displayed conflict with each other, such as by showing green lights at intersecting streets. This can happen if, say, a lightning strike creates a power surge that damages the solid state traffic controller switch and causes it to display conflicting green lights. A conflict monitor circuit detects the conflict and initiates remedial action to prevent accidents, such as changing all

of the signals to a flashing-red mode. However, using existing conflict monitor circuits designed for incandescent lamp signals with more modern LED signals can cause false conflict detection. The claimed conflict monitor compatibility circuit solves this problem, and also maintains the low power consumption that is one reason for lighting traffic signals with LEDs in the first place.

13. One source of the false-conflict problem is a difference between the electrical characteristics of LEDs and incandescent lamps. An incandescent lamp that is switched on has a relatively high resistance while generating light. When power to the lamp is off, it exhibits a much lower resistance (impedance). Conflict monitor circuits sense that a lamp is off when a relatively low voltage is present due to the low lamp resistance. When operating properly, the conflict monitor circuit detects if the voltages associated with crossing streets' green lights exceed a predetermined value, indicating that the green lights for both streets are on at the same time. If so, the conflict monitor circuit assumes a traffic controller switch malfunction and changes the intersection to an all-flashing-red mode.

14. LED signals are different because, unlike incandescent lamps, they typically exhibit a relatively high input impedance in the presence of even low currents, such as normal leakage currents from a solid state traffic controller switch that is turned off. These leakage currents do not cause a problem with incandescent lamps because incandescent lamps have a relatively low impedance at these low leakage currents. But with an LED traffic signal, the voltage can be appreciable even when the traffic control switch is turned off. So when LEDs are combined with conflict monitor circuits that use elevated voltage to indicate the existence of a conflict (two "on" green lights at crossing streets), false conflict determinations can occur even if the traffic controller switch is functioning properly. This is because leakage currents, which are present

during normal operation of the solid state traffic controller, are not shunted from the conflict monitor circuit by LED signals as they would be by incandescent lamps. In other words, a green-light LED signal subjected to leakage currents can create a high-voltage "false positive," which the conflict monitor circuit interprets as a lighted LED, even if it is not in fact lit. See original '645 patent, col. 5, lines 15-30; Hildebrand, col. 1, lines 11-33.

15. There were solutions to this problem before the claimed conflict monitor compatibility circuit, but none of them enabled full advantage to be taken of the low power consumption of LEDs as compared to other types of illuminating devices such as incandescent lamps or luminescent (neon or fluorescent) lights. One solution was placing a large capacitor across the inputs to the LEDs to absorb the leakage currents. This defeated the purpose of using LEDs for their low power consumption because of the reactive power drawn by the capacitor. See original '645 patent, col. 5, lines 23-30. Another solution is shown in Hildebrand, which was used to reject the claims, but as discussed below, Hildebrand's "dynamic load circuit," like a capacitor, also mitigates the advantages of using LEDs in the first place.

16. The following language in particular distinguishes the claimed invention from prior art traffic signal circuitry such as that shown in Hildebrand:

> a conflict monitor compatibility circuit including a low impedance load and a transistor in series connection with the low impedance load, the transistor being biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is within the operating range and an essentially conductive condition if the electrical input voltage drops below a predetermined value lower than the operating range, wherein the transistor in the essentially conductive condition couples the low impedance load to the electrical input for shunting leakage current from the solid state traffic controller switch when the switch is off.

17. The claimed conflict monitor compatibility circuit includes a transistor biased as a switch, so that a low impedance load is either out of the circuit (the transistor is in the essentially

nonconductive condition), whenever the electrical input voltage is within its operating range, or is coupled to the electrical input (the transistor is in the essentially conductive condition), if the electrical input voltage drops below a predetermined value lower than the operating range. The essentially nonconductive condition thus exists any time the solid state traffic controller switch is on, meaning that the electrical input voltage is in its operating range (between, say, 85 and 140 volts; see original '645 patent, col. 6, lines 27-30, col. 7, lines 63-67). However, if the electrical input voltage drops below a predetermined value (say, 40 volts; see original '645 patent, col. 7, lines 41-46), which indicates that the solid state traffic controller switch is off and the sensed voltage is due to leakage currents, the transistor is in its essentially conductive condition. This couples the low impedance load to the electrical input to reduce the leakage voltage to a value that is consistent with the proper operation of the conflict monitor circuit (say 10 volts; see original '645 patent, col. 7, lines 47-48). Shunting the leakage current through the low impedance load in this manner enables proper operation of the conflict monitor circuit because the artificially elevated leakage voltage cannot trigger a false conflict. In other words, the conflict monitor circuit will detect a low voltage (indicative of a low impedance), just as it would if the traffic signal used incandescent lamps, thus making prior art conflict monitor circuits compatible with LED-lit signals by preventing high-voltage, "false positive" conflict indications.

18. During the pendency of the present application, the Examiner has contended that Hildebrand's dynamic load circuit shown in Fig. 1A corresponds to the present conflict monitor compatibility circuit. The Examiner has equated Hildebrand's MOSFET transistor Q3 and resistor R7 to the transistor and low impedance load, respectively, of the conflict monitor compatibility circuit as claimed in prior versions of claims 24, 28, 32, and 44.

19. Hildebrand's circuit operates in a manner that at first glance might seem similar to the claimed conflict monitor compatibility circuit. One of the purposes of Hildebrand's "dynamic load circuit" is to deal with leakage currents from a solid state controller switch. Col. 1, lines 15-18. Hildebrand says that its dynamic load circuit ensures that in a power-off condition "external alternating leakage current cannot create appreciable voltages at the input terminals." Col. 6, lines 60-65. Finally, Hildebrand recognizes that leakage current can cause a false conflict indication. Col. 1, lines 28-41.

20. But Hildebrand's circuit for solving this problem differs from the conflict monitor compatibility circuit claimed in the present application. A major difference between Hildebrand's dynamic load circuit and the claimed conflict monitor compatibility circuit resides in the transistor coupled to the electrical input, which transistor is "biased as a switch having an essentially nonconductive condition whenever the electrical input voltage is within the operating range and an essentially conductive condition if the electrical input voltage drops below a predetermined value lower than the operating range." This transistor is different from Hildebrand's MOSFET Q3 in both structure and function.

21. The claimed transistor of the present application is "biased as a switch," and Hildebrand's MOSFET Q3 is an amplifier. These are mutually exclusive ways to structure a transistor. See, for example, Lovell, B., et al., Lecture 12: 9E103 Electrical Physics and Electronics, University of Queensland, Nov. 5, 2000, http://www.itee.uq.edu.au/~engg1030/lectures/1perpage/lect12.pdf#search=%22lecture%2012%20transistor%22, last visited October 12, 2006 (copy attached as Exhibit A). As explained in Lovell at pages 1-6, a transistor used as an amplifier is biased to ensure that the transistor

operates in a desired current range. Hildebrand's Fig. 4 shows the operating range of the MOSFET amplifier transistor Q3; at column 6, lines 17-36, Hildebrand discusses the circuitry that provides the operating characteristics shown in Fig. 4. At page 10, Lovell sums up the difference between a transistor amplifier (like Hildebrand's MOSFET Q3) and a transistor switch (like that claimed):

- For an amplifier, we want the transistor to operate in the linear region between cutoff and saturation [the dot-dash phantom line in Hildebrand's Fig. 4]
- For a switch, we drive the transistor between cutoff and saturation regions.

22. Thus, the claimed circuit operates differently from Hildebrand's. The claimed transistor switch is in "an essentially nonconductive condition whenever the electrical input voltage is within the operating range." In contrast, Hildebrand's MOSFET Q3 is in an essentially conductive condition even in the operating range (nominally 115 volts a.c., see col. 2, line 32).

23. This is seen in Hildebrand's Fig. 4, and is described at column 6, lines 11-15: "the circuit is such that the current decreases over part of its operating region with increasing voltage. This characteristic is shown, for example, in the curve of Fig. 4." In other words, although Q3's conductivity varies, it is not in a nonconductive condition <u>whenever</u> the electrical input voltage is in the operating range. The current-voltage characteristic of MOSFET Q3 (the dot-dash phantom line in Fig. 4) confirms that Q3 conducts throughout the device's operating region (when leakage currents are not present), with its conductivity increasing linearly as the voltage decreases. It is true that Hildebrand's MOSFET Q3 is conductive in the presence of leakage currents from the solid state switch controlling the traffic signal (see, for example, col. 1, lines 15-18). But the solid line in Fig. 4 shows that <u>Hildebrand's MOSFET is also conductive in the operating range</u>.

24. I performed tests that further demonstrate the differences between the claimed conflict monitor compatibility circuit and Hildebrand's dynamic load circuit. The test results are presented in Exhibit 4 to the previous Hochstein Declaration (a copy of Exhibit 4 is attached as Exhibit B).

25. Exhibit B directly compares the voltage-current characteristic of Hildebrand's circuit with that of the claimed conflict monitor compatibility circuit. The plot in Exhibit B labeled "Hildebrand Current" was generated using a circuit built in accordance with Hildebrand's disclosure. The voltage and current were measured at the input (the fused circuit lines at the far left in Hildebrand's Fig 1A). That plot closely matches the shape of the voltage-current characteristic in Fig. 4 of Hildebrand, in which the MOSFET transistor Q3 is conductive at essentially all voltages. In sharp contrast, the plot for the claimed switch-biased transistor/low impedance load ("Relume's Current") is conductive at low voltages, but is nonconductive at voltages above about 20 VAC. The current and voltage were measured at the electrical input 22 (downstream of the solid state traffic controller switch) in a circuit as shown in Fig. 5.

26. The second plot comprising Exhibit B shows the drastic difference between the power dissipated by Hildebrand's circuit as compared to almost no power dissipation using the claimed circuit. This plot illustrates at a glance that the claimed invention slashes the power consumption of Hildebrand's circuit. Hildebrand's low impedance load (resistor R7) remains in the circuit, drawing current, even in the operating range. But because the claimed switching transistor is in a nonconductive condition in the operating range (that is, when there is no leakage current), the low impedance load is completely out of the circuit during normal operation. Thus, the claimed circuit preserves one of the main reasons for using LEDs in the first place: their low

power consumption. For example, at 115 VAC, Hildebrand's dynamic load circuit consumes about 2.4 watts, while the claimed circuit would consume only 0.3 watts. Thus, the amount of power consumed by Hildebrand's dynamic load circuit during normal operation would be a significant fraction of the total power consumed by an LED traffic signal, typical ratings for which at the time of the present invention were about 14-20 watts. Original '645 patent, col. 1, line 62, to col. 2, line 2. Indeed, more recent LED traffic signals are rated as low as 6 watts, making the claimed circuit even more advantageous as compared to Hildebrand's dynamic load circuit. "Hi-Flux LED Modules – 433 Series Traffic Signals," Dialight Specification Sheet, http://www.dialight.com/pdf/TrafficSignals/MDTS433EXCAL001_A-W.pdf, last visited October 12, 2006 (copy attached as Exhibit C).

27. Another way of comparing the claimed conflict monitor compatibility circuit to Hildebrand is to consider whether it would have been obvious to replace Hildebrand's MOSFET transistor amplifier Q3 with a switch-biased transistor having the claimed operational properties. When viewed from that perspective, it is even clearer that Hildebrand would not have suggested the claimed circuit. No prior art document I am aware of suggests making such a substitution, nor that it would result in a drastic reduction in power consumption. In fact, there would have been little motivation to use the claimed compatibility circuit, with its lower power consumption, in Hildebrand's luminescent-tube signal, since the 2.4 watts consumed by Hildebrand's dynamic load circuit at the nominal operating voltage is still a relatively small fraction of the power consumed by the typical fluorescent or neon lamp.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that the

statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title XVIII of United States Code, and that such willful false statements made jeopardize the validity of this application or any patent issued thereon.

Date: April 12, 2007

Peter A. Hochstein

Peter A. Hochstein

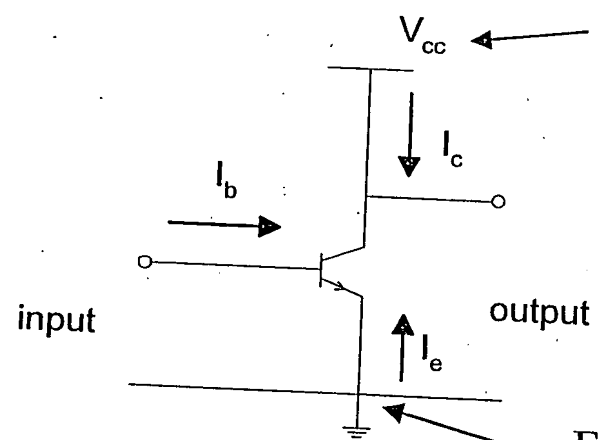
Exhibit A

To

EXHIBIT G

Transistor as an Amplifier

- How do we use the transistor as an amplifier?
- First, we must connect it appropriately to the supply voltages, input signal, and load, so it can be used
- A useful mode of operation is the common-emitter configuration

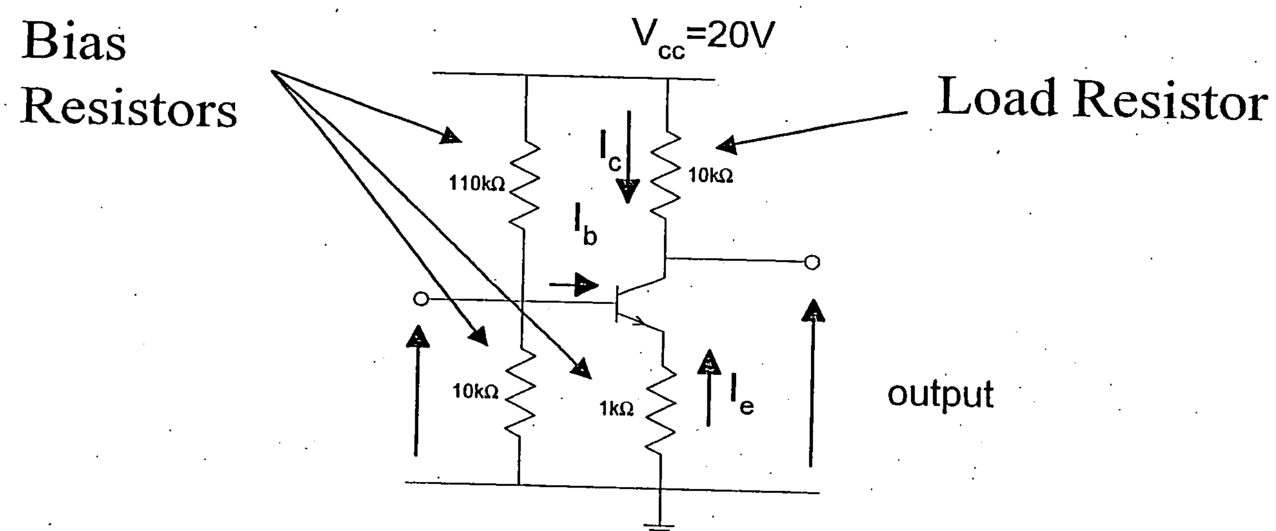


Voltage connected to collectors - positive supply voltage

Emitter common to both input and output

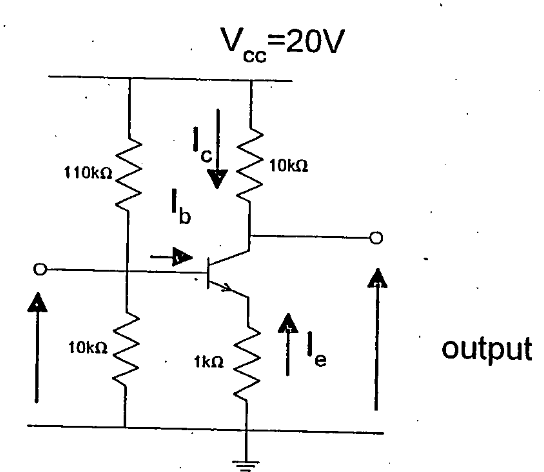
Common Emitter Configuration

- To make a practical circuit, we have to add bias and load resistors to ensure the transistor is at the desired operating point (operating in the right current range)

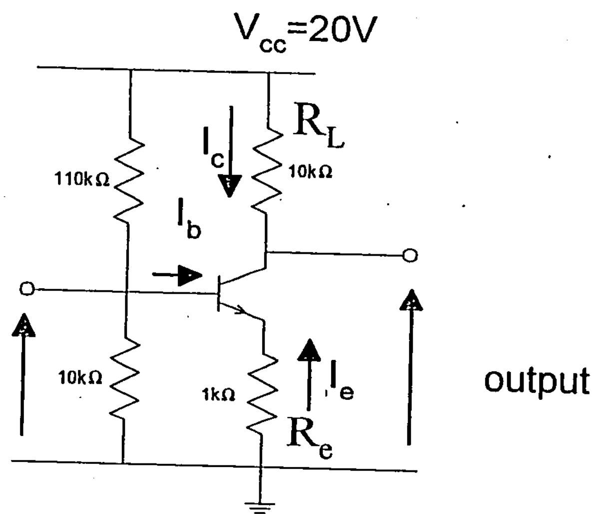


Bias and Load Resistors

- The resistors connected to the base ensure that the BE junction is forward biased. They effectively form a potential divider to reduce the voltage supplied to the base.
- The emitter resistor work with the base resistors to stabilise the operating point wrt variations in β due to component variation and temperature by providing negative feedback.
- Finally, the collector resistor provides the load



Circuit Analysis

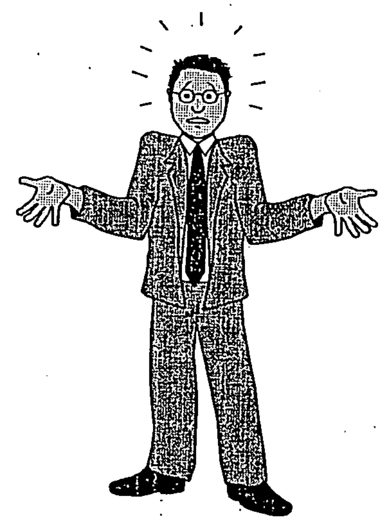


- Assume I_b is small so can be neglected
- Current through base resistors is 20/(110+10) =1/6 mA
- Voltage at base =1/6 * 10 $\cong$ 1.7V
- Therefore EB junction is forward biased
- Voltage at emitter $\cong$ 1.7-0.7=1.0V
- Current I_e = -1.0mA
- Current Ic = $-\alpha$Ie $\cong$ -Ie =1.0mA
- Voltage at collector = 20 -1*10=10V
- We usually set the collector voltage to be halfway between V_{cc} and 0V

> •A number of approximations have been made, but a more careful analysis will yield much the same result

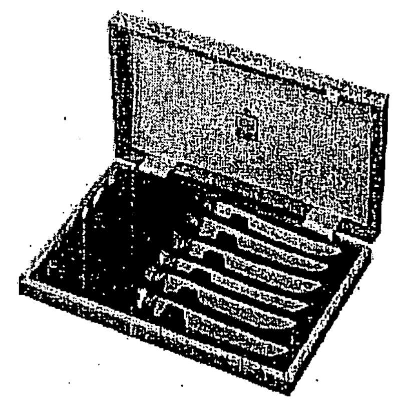
How it works

- A signal, such as music from a CD player, is applied to the input
- Let's examine what happens when such a signal increases the base voltage by ΔV_{in}.
- The emitter voltage is always 0.7V below V_b, so if V_b changes by ΔV_{in}, so does V_e.
- Thus the emitter current increases by $\Delta V_{in} / R_e$.
- But $I_c = -\alpha I_e \cong -I_e$, so it also increases by $\Delta V_{in} / R_e$.
- Thus the voltage at the collector will increase by $-\Delta V_{in} R_L / R_e$ (that is, it will decrease)
- In this case R_L/R_e is 10, so the circuit amplifies the input voltage signal by a factor of -10.
- In general, the gain is $-R_L/R_e$. The negative sign indicates that a increase in input voltage leads to a decrease in output voltage.
- This is an example of an inverting amplifier



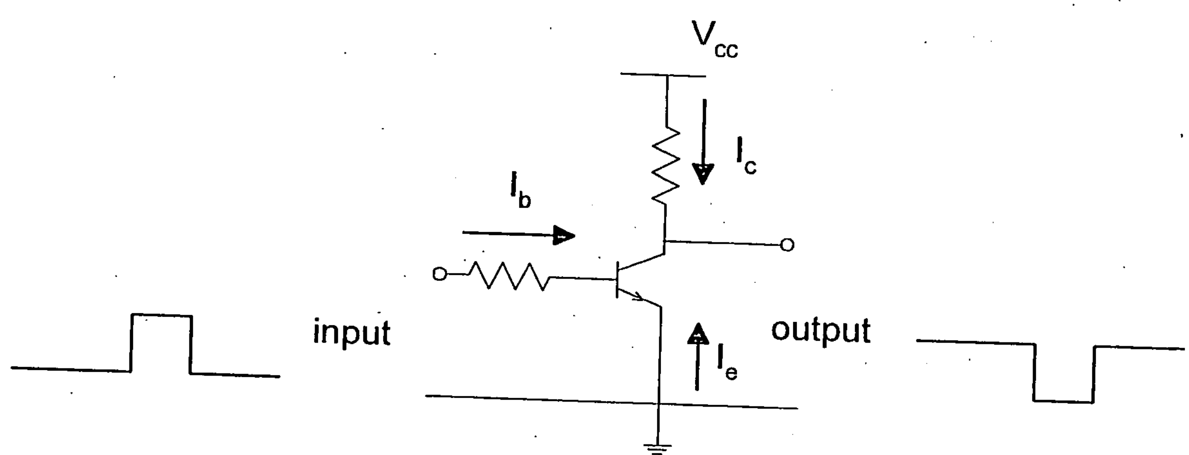
Do You Want More?

- If you want more gain, you can can connect the output of one amplifier stage to the input of another resulting in an overall gain of 10x10=100.
- Another way to increase gain is to decrease R_L or decrease R_e, but other factors come into play which limit this approach.
- For AC (e.g. music) signals, another method to increase the gain is to put a capacitor in series with R_e.
- This effectively shorts R_e at high frequencies and leads to large increases in gain.
- Detailed design issues will be covered in 3E202 in second year.
- If you want even more gain, use an op amp (see later)



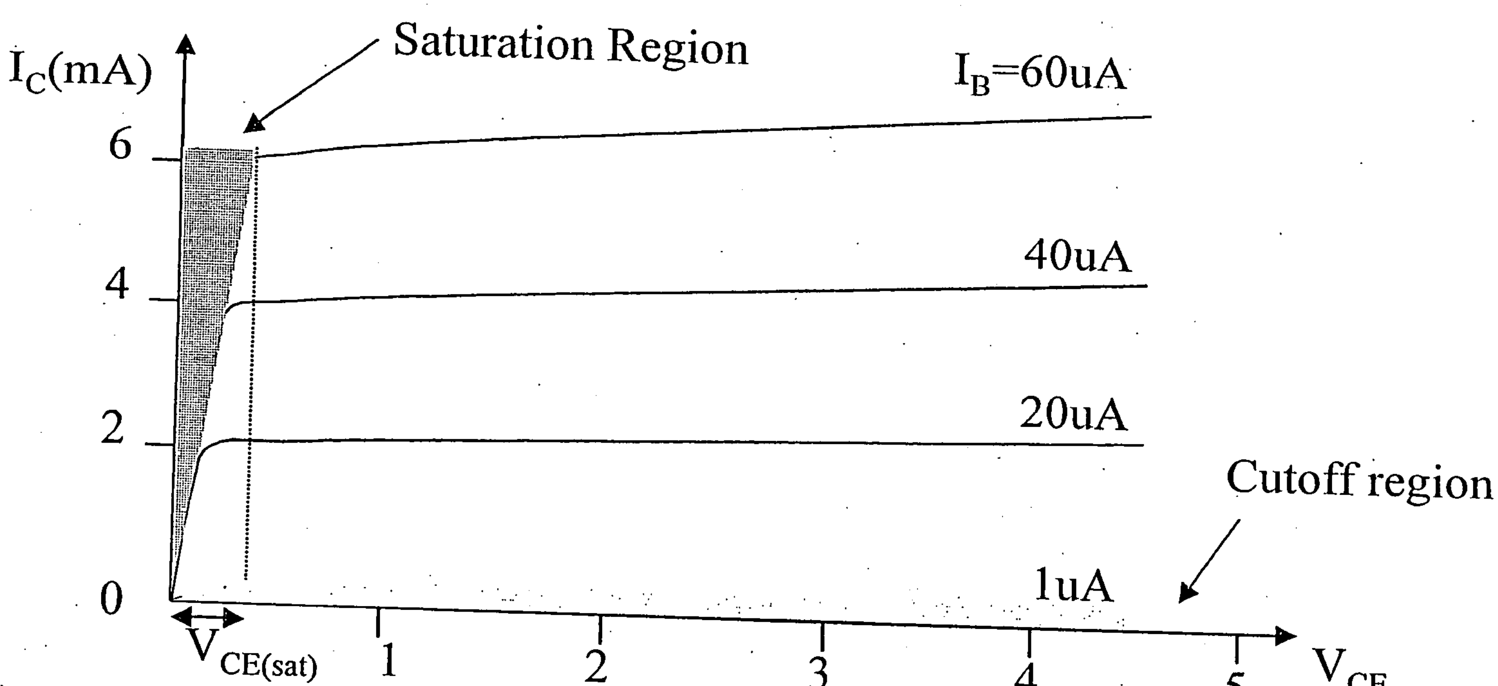
Transistor as a Switch

- In many digital circuit applications, the transistor is merely used as a switch.
- This means we can ignore fancy biasing circuitry and just turn the device off (*cut-off region*) or on (*saturation region*)
- Some early digital circuitry used resistors and transistors as indicated (RTL)

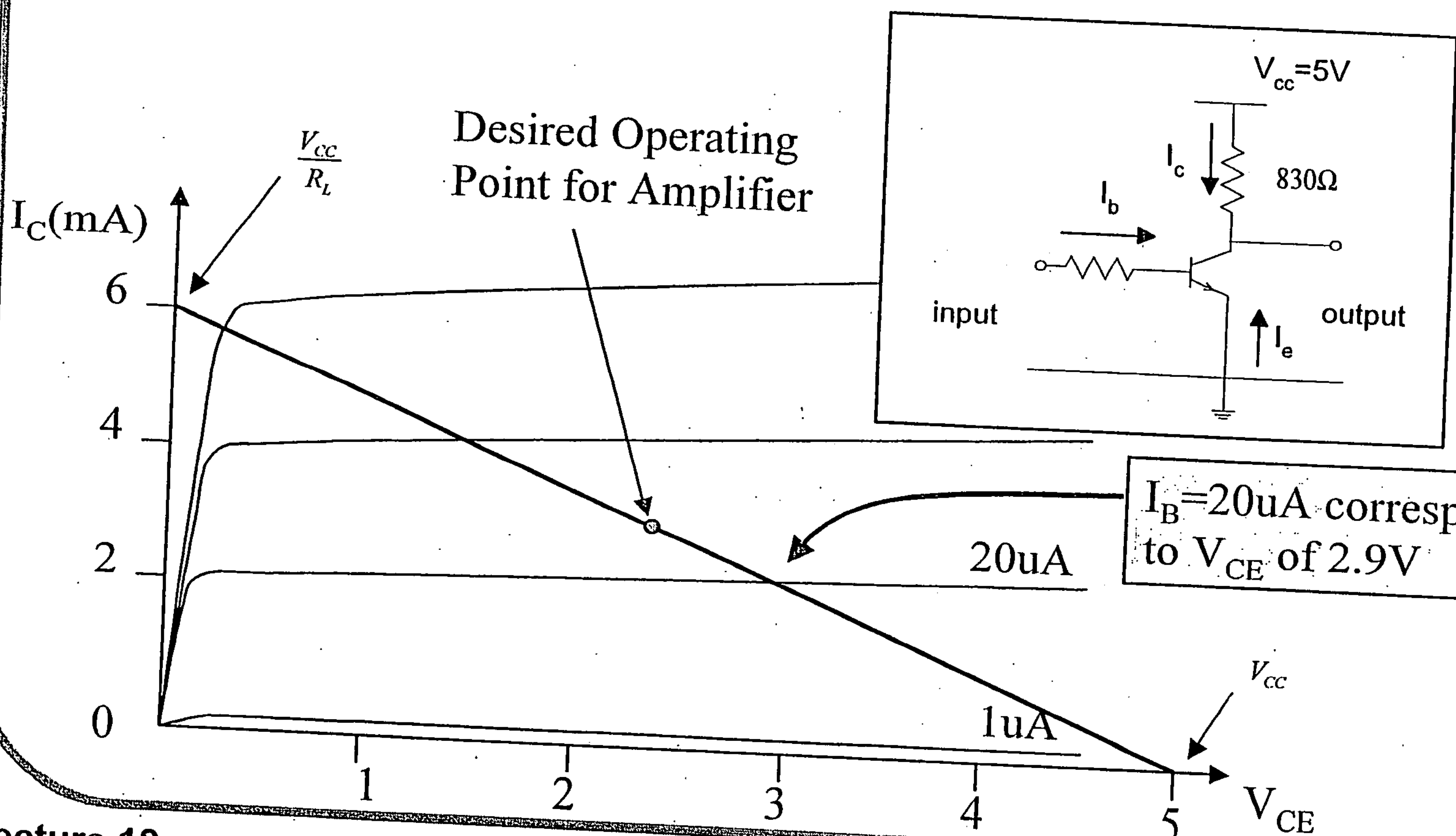


Characteristic Curves

- Characteristic curves fully describe the operation of a transistor



Load Lines



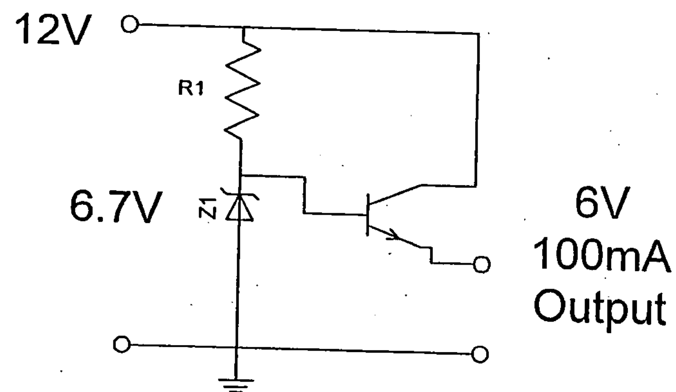
I_B=20uA corresponds to V_{CE} of 2.9V

Comments

- For an amplifier, we want the transistor to operate in the linear region between cutoff and saturation.
- For a switch, we drive the transistor between cutoff and saturation regions.

Improved Voltage Regulator

- Buffer regulated zener diode output with transistor in *emitter follower* (common collector) configuration.
- Current output from zener boosted by β (50-200)
- Less current drawn in standby mode
- Need to boost zener voltage by 0.7V.



Relay Driver

- Here the transistor is used as a switch to close relay contacts by driving the coil.
- Note the need for the *flyback* diode to prevent damage to the transistor from the high voltages created by the coil when the current is switched off.

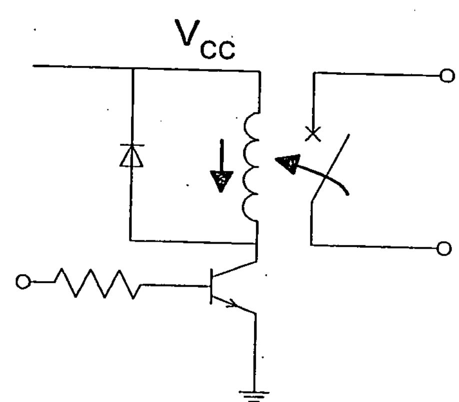
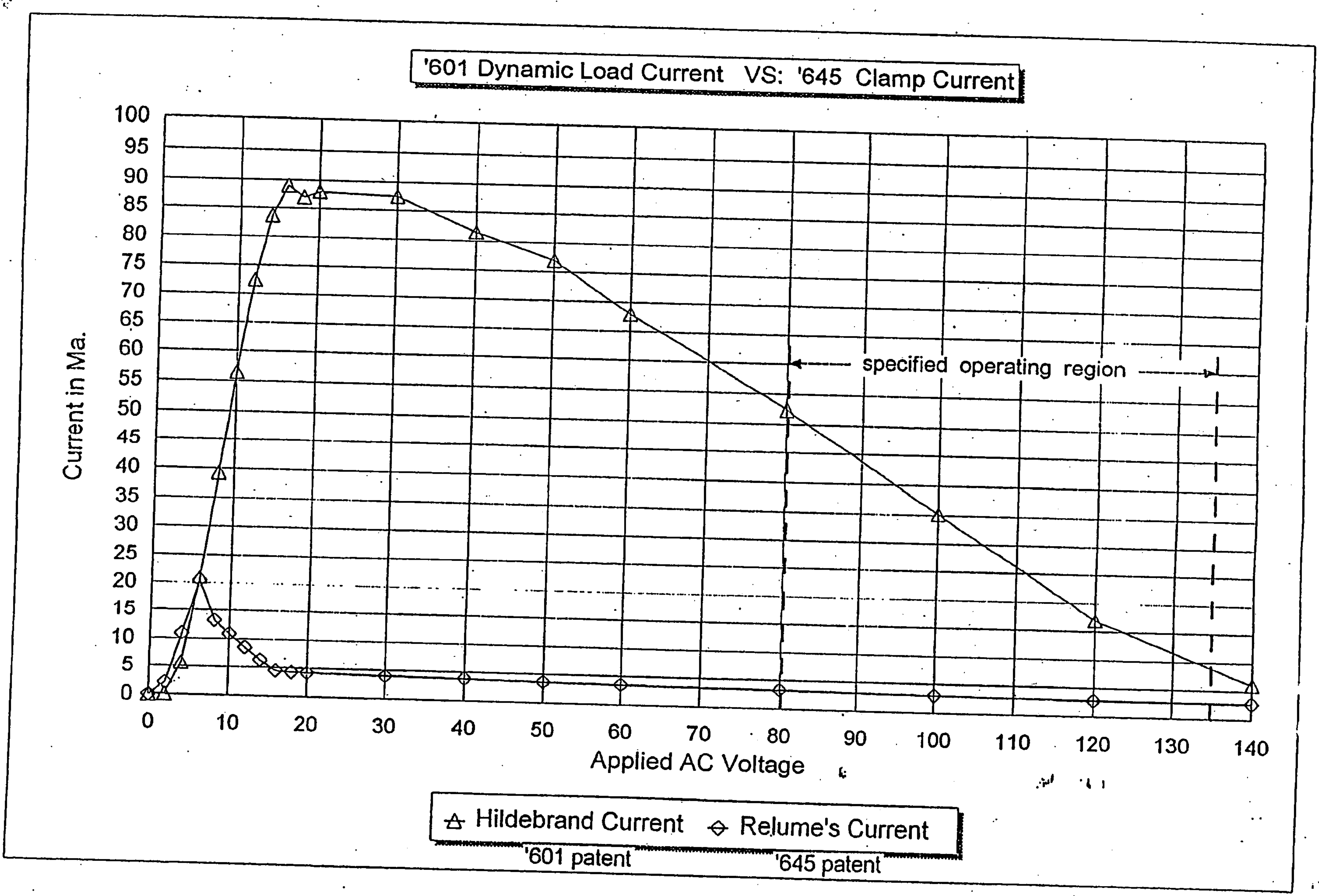


Exhibit B

To

EXHIBIT G



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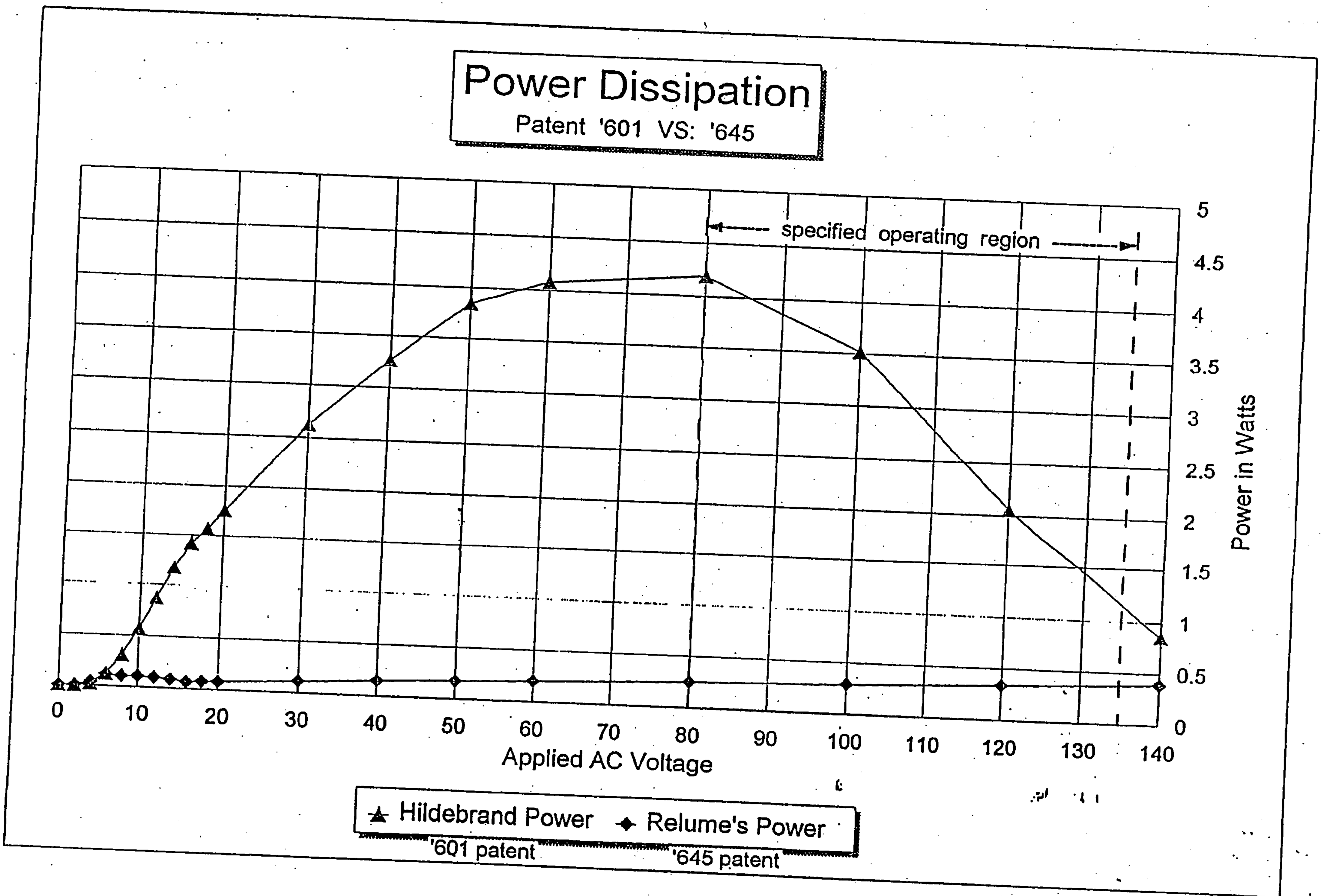

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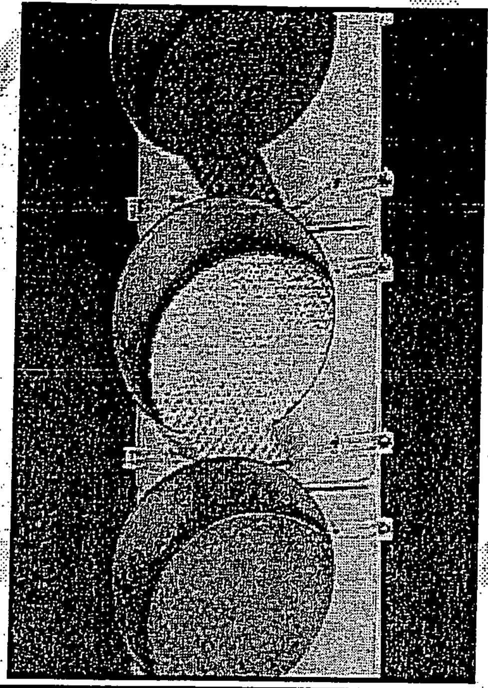
Exhibit C

To

EXHIBIT G

Dialight

HI-FLUX LED MODULES
433 Series TRAFFIC SIGNALS



Lighting Uniformity. ITE Conformity.

FEATURES / BENEFITS

- ▲ All modules (including yellow) meet the ITE VTCSH-LED Circular Signal Supplement over the full temperature range of -40°C to +74°C
- ▲ Robust Hi-Flux LED Technology
- ▲ Uniform non-pixilated illumination
- ▲ Expanded view radiation pattern suitable for span wire and steep grade applications
- ▲ Fuse and transient suppressor incorporated for superior line and load protection
- ▲ ENERGY STAR® qualified
- ▲ 90% reduction in power vs. incandescent
- ▲ Long life: Up to 10 times longer than incandescent
- ▲ Convex tinted lens reduces glare and sun reflection
- ▲ Hard coated lenses for abrasion resistance
- ▲ Easy to install into existing signal enclosure

SPECIFICATIONS

- ▲ Operating Voltage Range: 80VAC to 135VAC (120VAC nominal)
- ▲ Operating Temperature Range: -40°C to +74°C
- ▲ Turn-on / Turn-off Time < 75 msec
- ▲ Power Factor > 0.9
- ▲ Total Harmonic Distortion < 20%
- ▲ Meets FCC Title 47, Subpart B, Section 15 regulations for electrical noise
- ▲ Failed State Impedance > 250K ohm within 300ms
- ▲ Conforms to MIL-STD-810F for blowing rain
- ▲ Conforms to MIL-STD-883, Test Method 2007, for mechanical vibration
- ▲ Conforms to MIL-STD-883, Test Method 1010, temperature cycling requirements
- ▲ Provided with quick connect terminals and spade adapters
- ▲ Written manufacturer's warranty available on request
- ▲ All products traceable by serial number
- ▲ Luminance uniformity and color uniformity exceed ITE VTCSH-LED Circular Signal Supplement requirements
- ▲ Transient suppression exceeds ITE VTCSH-LED Circular Supplement requirements and meets the following standards:
  - NEMA TS-2 Sec. 2.1.6 and Sec. 2.1.8
  - IEC 1000-4-5, 3KV, 2 ohm source impedance
  - ANSI/IEEE C62, 41-2002; IEC 61000-4-12, 6KV, 200A, 100KHz ring wave
- ▲ Power supply is conformally coated for robust operation

A4703 ISO 9001

Dialight Corporation

Dialight Corporation
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MDTS433EXCAL001_A

Dialight

Lighting Uniformity. ITE Conformity.

Hi-Flux LED MODULES
433 Series TRAFFIC SIGNALS

8" (200MM) 120VAC SIGNAL MODULES

Part Number	Color	Lens Type	Dominant Wavelength (nm)	Typical Wattage at 25°C	Peak Minimum Maintained Luminous Intensity (cd)	ENERGY STAR® Qualified*
433-1110-003X	Red	Tinted	625	6	165	✔
433-3130-001X	Yellow	Tinted	590	13	410	
433-2120-001X	Green	Tinted	500	6	215	✔
433-2170-001X	Green	Clear	500	6	215	✔

12" (300MM) 120VAC SIGNAL MODULES

Part Number	Color	Lens Type	Dominant Wavelength (nm)	Typical Wattage at 25°C	Peak Minimum Maintained Luminous Intensity (cd)	ENERGY STAR® Qualified*
433-1210-003X	Red	Tinted	625	9	365	✔
433-3230-001X	Yellow	Tinted	590	16	910	
433-2220-001X	Green	Tinted	500	12	475	✔
433-2270-001X	Green	Clear	500	12	475	✔

* Currently Yellow Modules and Arrows are not eligible.

A4703 ISO 9001

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EXHIBIT H

OIPE IAP5
APR 1 3 2007
PATENT & TRADEMARK OFFICE

Attorney Docket No.: 9100.2881 REI
U.S. Patent Appln. No. 09/382,702
For: POWER SUPPLY FOR LIGHT EMITTING DIODE ARRAY
Date: April 13, 2007

The stamp of the US Patent Office hereon will acknowledge receipt of the following:

1. Amendment and attached Appendix
2. Declaration of Peter A. Hochstein, with Exhibits A-C
3. Submission of Amended Drawing, with a new sheet of formal drawings and a marked-up copy showing the changes
4. Supplemental Declaration, executed by the inventor
5. Copy of Form PTO/SB/08B listing two documents from the Amendment Under 37 C.F.R. § 41.33 dated October 13, 2006.

RECEIVED
APR 1 2006
By

Pike Expedition, November 1806, Rocky Mountains

DAVID M. QUINLAN, P.C.
32 NASSAU STREET
SUITE 300
PRINCETON, NJ 08542

EXHIBIT I

09/382,702	POWER SUPPLY FOR LIGHT EMITTING DIODE ARRAY	05-07-2009::10:56:34

This application is officially maintained in electronic form. To View: Click the desired Document Description. To Download and Print: Check the desired document(s) and click PDF.

Bibliographic Data

Mail Room Date	Document Code	Document Description	Document Category	Page Count
01-22-2009	CTNF	**Non-Final Rejection**	**PROSECUTION**	**11**
01-22-2009	SRFW	Search information including classification, databases and other search related notes	PROSECUTION	1
09-12-2008	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	3
09-12-2008	CLM	Claims	PROSECUTION	15
09-12-2008	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	5
09-12-2008	WFEE	Fee Worksheet (PTO-875)	PROSECUTION	1
08-27-2008	LET.	Miscellaneous Incoming Letter	PROSECUTION	2
08-12-2008	CTNF	Non-Final Rejection	PROSECUTION	16
08-12-2008	892	List of references cited by examiner	PRIOR ART	1
08-12-2008	SRFW	Search information including classification, databases and other search related notes	PROSECUTION	1
07-25-2008	N416	Notice of Withdrawal from Issue Branch (PTOL-67)	PROSECUTION	2
07-01-2008	N271	Response to Amendment under Rule 312	PROSECUTION	2
05-08-2008	M327	Miscellaneous Communication to Applicant - No Action Count	PROSECUTION	2
05-05-2008	IFEE	Issue Fee Payment (PTO-85B)	PROSECUTION	1
04-25-2008	N570	Communication - Re: Power of Attorney (PTOL-308)	PROSECUTION	1
04-25-2008	N570	Communication - Re: Power of Attorney (PTOL-308)	PROSECUTION	1
04-15-2008	A.NA	Amendment after Notice of Allowance (Rule 312)	PROSECUTION	1
04-15-2008	SPEC	Specification	PROSECUTION	1
04-15-2008	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	3
04-15-2008	DRW	Drawings-only black and white line drawings	PROSECUTION	1
04-15-2008	LET.	Miscellaneous Incoming Letter	PROSECUTION	5
04-15-2008	PA..	Power of Attorney	PROSECUTION	3
03-14-2008	CTMS	Miscellaneous Action with SSP	PROSECUTION	2
03-14-2008	1449	List of References cited by applicant and considered by examiner	PRIOR ART	1
02-11-2008	NOA	Notice of Allowance and Fees Due (PTOL-85)	PROSECUTION	3
02-11-2008	NOA	Notice of Allowance and Fees Due (PTOL-85)	PROSECUTION	3
02-11-2008	IIFW	Issue Information including classification, examiner, name, claim, renumbering, etc.	PROSECUTION	1
		Search information including		

02-11-2008	SRFW	classification, databases and other search related notes	PROSECUTION	1
02-04-2008	SRNT	Examiner's search strategy and results	PROSECUTION	1
12-12-2007	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	1
12-12-2007	CLM	Claims	PROSECUTION	16
12-12-2007	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	8
12-12-2007	APPENDIX	Appendix to the Specification	PROSECUTION	15
12-12-2007	OATH	Oath or Declaration filed	PROSECUTION	1
12-12-2007	XT/	Extension of Time	PROSECUTION	2
12-12-2007	WFEE	Fee Worksheet (PTO-875)	PROSECUTION	1
07-16-2007	CTNF	Non-Final Rejection	PROSECUTION	11
07-16-2007	1449	List of References cited by applicant and considered by examiner	PRIOR ART	1
07-16-2007	SRFW	Search information including classification, databases and other search related notes	PROSECUTION	1
07-02-2007	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	2
07-02-2007	DRW	Drawings-only black and white line drawings	PROSECUTION	1
06-25-2007	NTC.A.NONCPL	Notice to the applicant regarding a non-compliant or non-responsive amendment	PROSECUTION	2
04-13-2007	AMSB	Amendment Submitted/Entered with Filing of CPA/RCE	PROSECUTION	1
04-13-2007	CLM.NE	Claim-Amendment Not Entered	PROSECUTION	16
04-13-2007	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	25
04-13-2007	NDRW	New or Additional Drawings	PROSECUTION	2
04-13-2007	DRW.NE	Drawings - Amendment Not Entered	PROSECUTION	1
04-13-2007	AF/D	Rule 130, 131 or 132 Affidavits	PROSECUTION	14
04-13-2007	OATH	Oath or Declaration filed	PROSECUTION	1
04-13-2007	IDS	Information Disclosure Statement (IDS) Filed (SB/08)	PROSECUTION	1
04-13-2007	NPL	NPL Documents	PRIOR ART	14
04-13-2007	NPL	NPL Documents	PRIOR ART	2
04-13-2007	WFEE	Fee Worksheet (PTO-875)	PROSECUTION	1
01-19-2007	CTAV	Advisory Action (PTOL-303)	PROSECUTION	2
01-19-2007	SRFW	Search information including classification, databases and other search related notes	PROSECUTION	1
01-16-2007	RCEX	Request for Continued Examination (RCE)	PROSECUTION	1
01-16-2007	XT/	Extension of Time	PROSECUTION	2
11-03-2006	N570	Communication - Re: Power of Attorney (PTOL-308)	PROSECUTION	2
10-13-2006	PA..	Power of Attorney	PROSECUTION	2
10-13-2006	AP/A	Amendment/Argument after Notice of Appeal	PROSECUTION	1
10-13-2006	CLM	Claims	PROSECUTION	15
10-13-2006	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	26
10-13-2006	AF/D	Rule 130, 131 or 132 Affidavits	PROSECUTION	12

10-13-2006	OATH	Oath or Declaration filed	PROSECUTION	1
10-13-2006	XT/	Extension of Time	PROSECUTION	2
10-13-2006	IDS	Information Disclosure Statement (IDS) Filed (SB/08)	PROSECUTION	1
10-13-2006	NPL	NPL Documents	PRIOR ART	12
10-13-2006	NPL	NPL Documents	PRIOR ART	2
10-13-2006	LET.	Miscellaneous Incoming Letter	PROSECUTION	4
10-13-2006	WFEE	Fee Worksheet (PTO-875)	PROSECUTION	1
07-24-2006	PA..	Power of Attorney	PROSECUTION	2
07-13-2006	CTMS	Miscellaneous Action with SSP	PROSECUTION	2
05-26-2006	CTMS	Miscellaneous Action with SSP	PROSECUTION	2
04-24-2006	N572	Response - Re: Informal Power of Attorney (PTOL-308)	PROSECUTION	1
04-14-2006	LET.	Miscellaneous Incoming Letter	PROSECUTION	1
04-14-2006	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	1
04-14-2006	XT/	Extension of Time	PROSECUTION	1
04-14-2006	PA..	Power of Attorney	PROSECUTION	1
04-13-2006	PA..	Power of Attorney	PROSECUTION	3
03-13-2006	AP.B	Appeal Brief Filed	PROSECUTION	1
03-13-2006	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	2
03-13-2006	XT/	Extension of Time	PROSECUTION	1
01-13-2006	CTMS	Miscellaneous Action with SSP	PROSECUTION	2
08-29-2005	LET.	Miscellaneous Incoming Letter	PROSECUTION	1
05-02-2005	AP.B	Appeal Brief Filed	PROSECUTION	4
02-28-2005	CTFR	Final Rejection	PROSECUTION	13
02-28-2005	SRFW	Search information including classification, databases and other search related notes	PROSECUTION	1
05-14-2004	WFEE	Fee Worksheet (PTO-875)	PROSECUTION	1
05-14-2004	FWCLM	Index of Claims	PROSECUTION	1
05-07-2004	A.NE	Amendment After Final	PROSECUTION	1
05-07-2004	CLM	Claims	PROSECUTION	20
05-07-2004	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	2
05-07-2004	AP.B	Appeal Brief Filed	PROSECUTION	139
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11-24-2003	AP.B	Appeal Brief Filed	PROSECUTION	30
11-24-2003	APPENDIX	Appendix to the Specification	PROSECUTION	113
11-07-2003	N/AP	Notice of Appeal Filed	PROSECUTION	1
09-04-2003	CTFR	Final Rejection	PROSECUTION	10
06-18-2003	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	2
06-18-2003	CLM	Claims	PROSECUTION	25
06-18-2003	XT/	Extension of Time	PROSECUTION	2
01-15-2003	CTNF	Non-Final Rejection	PROSECUTION	6
06-11-2002	LET.	Miscellaneous Incoming Letter	PROSECUTION	4
06-11-2002	IDS	Information Disclosure Statement (IDS) Filed (SB/08)	PROSECUTION	2
06-11-2002	1449	List of References cited by applicant and considered by examiner	PRIOR ART	1
08-29-2001	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	1

08-29-2001	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	2
08-29-2001	DIST	Terminal Disclaimer Filed	PROSECUTION	1
03-21-2001	PETDEC	Petition Decision	PROSECUTION	2
03-06-2001	LET.	Miscellaneous Incoming Letter	PROSECUTION	1
03-06-2001	PET.	Petition Entered	PROSECUTION	2
03-06-2001	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	1
03-06-2001	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	2
03-06-2001	OATH	Oath or Declaration filed	PROSECUTION	1
03-06-2001	IDS	Information Disclosure Statement (IDS) Filed (SB/08)	PROSECUTION	1
03-06-2001	NPL	NPL Documents	PRIOR ART	9
02-28-2001	PET.	Petition Entered	PROSECUTION	3
02-28-2001	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	1
02-28-2001	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	21
02-05-2001	LET.	Miscellaneous Incoming Letter	PROSECUTION	1
02-05-2001	DRW	Drawings-only black and white line drawings	PROSECUTION	6
01-30-2001	NOA	Notice of Allowance and Fees Due (PTOL-85)	PROSECUTION	3
01-30-2001	LET.	Miscellaneous Incoming Letter	PROSECUTION	1
01-09-2001	LET.	Miscellaneous Incoming Letter	PROSECUTION	1
01-09-2001	OATH	Oath or Declaration filed	PROSECUTION	1
01-03-2001	LET.	Miscellaneous Incoming Letter	PROSECUTION	1
01-03-2001	OATH	Oath or Declaration filed	PROSECUTION	1
11-08-2000	LET.	Miscellaneous Incoming Letter	PROSECUTION	4
11-03-2000	LET.	Miscellaneous Incoming Letter	PROSECUTION	2
10-27-2000	LET.	Miscellaneous Incoming Letter	PROSECUTION	1
10-27-2000	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	1
10-27-2000	CLM	Claims	PROSECUTION	3
10-27-2000	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	2
10-16-2000	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	1
10-16-2000	CLM	Claims	PROSECUTION	3
10-16-2000	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	2
09-07-2000	CTNF	Non-Final Rejection	PROSECUTION	4
06-12-2000	SPEC	Specification	PROSECUTION	17
06-12-2000	CLM	Claims	PROSECUTION	10
06-12-2000	ABST	Abstract	PROSECUTION	1
06-12-2000	A...	Amendment/Req. Reconsideration-After Non-Final Reject	PROSECUTION	1
06-12-2000	CLM	Claims	PROSECUTION	9
06-12-2000	REM	Applicant Arguments/Remarks Made in an Amendment	PROSECUTION	4
06-12-2000	IDS	Information Disclosure Statement (IDS) Filed (SB/08)	PROSECUTION	2
06-12-2000	1449	List of References cited by applicant and considered by examiner	PRIOR ART	1

04-25-2000	EXIN	Examiner Interview Summary Record (PTOL - 413)	PROSECUTION	2
04-20-2000	LET.	Miscellaneous Incoming Letter	PROSECUTION	2
04-20-2000	PA..	Power of Attorney	PROSECUTION	2
03-24-2000	CTNF	Non-Final Rejection	PROSECUTION	6
03-24-2000	892	List of references cited by examiner	PRIOR ART	1
03-24-2000	NFDR	Notice of Formal Drawings Required	PROSECUTION	2
03-24-2000	1449	List of References cited by applicant and considered by examiner	PRIOR ART	24
03-24-2000	LET.	Miscellaneous Incoming Letter	PROSECUTION	77
03-24-2000	IDS	Information Disclosure Statement (IDS) Filed (SB/08)	PROSECUTION	2
03-24-2000	1449	List of References cited by applicant and considered by examiner	PRIOR ART	1
12-08-1999	IDS	Information Disclosure Statement (IDS) Filed (SB/08)	PROSECUTION	2
12-08-1999	NPL	NPL Documents	PRIOR ART	12
12-08-1999	NPL	NPL Documents	PRIOR ART	23
08-24-1999	LET.	Miscellaneous Incoming Letter	AS FILED	39
08-24-1999	IIFW	Issue Information including classification, examiner, name, claim, renumbering, etc.	PROSECUTION	1
08-24-1999	SRFW	Search information including classification, databases and other search related notes	PROSECUTION	1
08-24-1999	FWCLM	Index of Claims	PROSECUTION	1
08-24-1999	TRNA	Transmittal of New Application	PROSECUTION	3
08-24-1999	136A	Authorization for Extension of Time all replies	PROSECUTION	3
08-24-1999	DRW	Drawings-only black and white line drawings	PROSECUTION	6
08-24-1999	SPEC	Specification	PROSECUTION	18
08-24-1999	CLM	Claims	PROSECUTION	10
08-24-1999	ABST	Abstract	PROSECUTION	1
08-24-1999	OATH	Oath or Declaration filed	PROSECUTION	2
08-24-1999	WFEE	Fee Worksheet (PTO-875)	PROSECUTION	1
08-24-1999	WFEE	Fee Worksheet (PTO-875)	PROSECUTION	1
08-24-1999	WCLM	Claims Worksheet (PTO-2022)	PROSECUTION	1

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EXHIBIT J

RELUME CORPORATION, Plaintiff, v. DIALIGHT CORPORATION, ECOLUX, INC., PRECISION SOLAR CONTROLS, INC., LUMILEDS LIGHTING BV, PHILIPS LIGHTING BV, and HEWLETT-PACKARD COMPANY, Defendants.

Case No. 98-CV-72360

UNITED STATES DISTRICT COURT FOR THE EASTERN DISTRICT OF MICHIGAN, SOUTHERN DIVISION

63 F. Supp. 2d 788; 1999 U.S. Dist. LEXIS 13116

August 26, 1999, Decided
August 26, 1999, Filed

DISPOSITION: [**1] Dialight's, Precision's and Lumileds' motions for noninfringement GRANTED on issue of literal noninfringement as to all asserted claims of *'645* and *'909 patents*. Ecolux's motion for noninfringement GRANTED on issue of literal noninfringement as to all asserted claims of *'645 patent* but DENIED on same issue as to asserted claims of *'909 patent*. Lumileds' anticipation motion GRANTED as to claim 1 of *'645 patent* and claims 1-3, 7, 10-12 and 16 of *'909 patent* but DENIED as to claims 2 and 4 of *'645 patent*. Lumileds' obviousness motion GRANTED as to claims 2, 4, 5 and 6 of *'645 patent* and claims 6, 9, 15 and 18 of *'909 patent*.

COUNSEL: For Plaintiff: Timothy J. Haller, Robert P. Greenspan, Niro, Scavone, Haller & Niro, Chicago, IL.

For Plaintiff: Edward J. Hood, Clark Hill, PLC, Detroit, MI.

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For ECOLUX, Defendant: Mark D. Roth, Patrick J. Nash, Jr., Pretzel & Stouffer, Chicago, IL.

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For PRECISION SOLAR CONTROLS, Defendant: Dennis J. Levasseur, Thomas G. Cecil, Bodman, Longley & Dahling LLP, Detroit, MI.

For HEWLETT-PACKARD, LUMILEDS LIGHTING, PHILIPS LIGHTING, Defendants: John M. DiMatteo, Patterson, Belknap, Webb & Tyler, LLP, New York, NY.

For HEWLETT-PACKARD, LUMILEDS LIGHTING, PHILIPS LIGHTING, Defendants: James R. Case, Kerr, Russell & Webber, PLC, Detroit, MI.

JUDGES: John Feikens, United States District Judge.

OPINION BY: John Feikens

OPINION

[*791] OPINION AND ORDER

Introduction

Before me is a multi-patent infringement dispute between competitors in the light emitting diode ("LED") traffic signal industry. At issue are summary judgment motions regarding patent noninfringement and validity filed by defendants Dialight Corporation ("Dialight"), Ecolux, Inc. ("Ecolux"), Precision Solar Controls, Inc. ("Precision"), Lumileds Lighting BV ("Lumileds"), Philips Lighting BV ("Philips"), and Hewlett-Packard Company ("Hewlett-Packard").

[**3] I. Background

All parties are involved in the design, development, manufacture, assembly, and/or sales of LED traffic signals. Most traffic signals in the United States use incandescent light bulbs, which produce light by heating a filament in the bulb's vacuum chamber with electric current. The heated filament gives off light. Simple incandescence is inefficient, however, since it wastes most of the electrical energy it consumes as heat.

LEDs offer a solution to this problem because they do not use a heated filament to produce light. Instead they use a tiny piece of specially formulated semiconductor material that emits light when an electric current passes through it. LEDs have existed for decades, and so has knowledge of their energy savings advantage over incandescent bulbs, but their use in traffic signals is a relatively new application.

On June 27, 1996, Peter Hochstein, a Relume employee, filed a patent application with the U.S. Patent Office, in which he claimed a variety of power supply inventions for retrofit LED arrays, i.e., arrays that can replace incandescent bulbs in devices originally built for incandescent illumination. On August 26, 1997, the Patent Office [**4] issued that application as *U.S. Patent No. 5,661,645 ("the '645 patent")*. The *'645 patent* lists Hochstein as its inventor.

On January 10, 1997, Hochstein filed another patent application with the Patent Office, in which he claimed various inventions related to a temperature compensation circuit for LEDs. This circuit functions as a feedback loop to prevent an LED's light intensity from decreasing as temperature increases. On July 21, 1998, the Patent Office issued this second application as *U.S. Patent No. 5,783,909*. The *'909 patent* lists Hochstein as its inventor.

Relume's suit against defendants alleges infringement of its *'645* and *'909 patents*. All defendants have argued in response that their accused products do not infringe Relume's patents. Three defendants - Lumileds, Philips, and Hewlett-Packard (collectively "Lumileds") - have also argued that Relume's patents are invalid and unenforceable in light of relevant prior art [*792] Relume did not make available to the Patent Office during the prosecution of its patents. Defendants' summary judgment motions address these issues. Relume has filed no summary judgment motions.

II. Summary Judgment Standard

Federal Rule of Civil [**5] *Procedure 56(c)* provides that a summary judgment shall issue "if the pleadings, depositions, answers to interrogatories, and admissions on file, together with the affidavits, if any, show that there is no genuine issue as to any material fact and that the moving party is entitled to a judgment as a matter of law." A genuine issue of material fact does not exist "where the record taken as a whole could not lead a rational trier of fact to find for the nonmoving party." *Matsushita Elec. Indus. Co. v. Zenith Radio Corp., 475 U.S. 574, 587, 89 L. Ed. 2d 538, 106 S. Ct. 1348 (1986).* The movant has the initial burden of showing that no genuine issue of material fact exists. See *Celotex Corp. v. Catrett, 477 U.S. 317, 323, 91 L. Ed. 2d 265, 106 S. Ct. 2548 (1986)*; see also *Fed. R. Civ. P. 56(c)*.

Once the movant meets this initial burden, the nonmovant "must set forth specific facts showing that there is a genuine issue for trial." *Fed. R. Civ. P. 56(e)*. These specific facts must constitute "sufficient evidence favoring the nonmoving party." *Anderson v. Liberty Lobby, Inc., 477 U.S. 242, 249, 91 L. Ed. 2d 202, 106 S. Ct. 2505 (1986).* [**6] Evidence that is "merely colorable" or "not significantly probative" will not demonstrate a need for trial. *Id. at 249-50*. Likewise, "the mere existence of a scintilla of evidence in support of the [nonmovant's] position will be insufficient; there must be evidence on which the jury could *reasonably* find for the [nonmovant]." *Id. at 252* (emphasis added).

The essence of the summary judgment inquiry is this: "whether the evidence presents a sufficient disagreement to require submission to a jury or whether it is so one-sided that one party must prevail as a matter of law." *Id. at 251-52*. In addressing this inquiry, I must

view the evidence, and all reasonable inferences drawn from it, "in the light most favorable to the party opposing the motion." *Matsushita, 475 U.S. at 587.*

III. Literal Infringement

In their summary judgment motions, all defendants assert literal noninfringement of claims 1, 2, 4, 5, and 6 of the *'645 patent*. As to the *'909 patent*, all defendants except Precision [1] assert literal noninfringement of claims 1 and 10 - the independent claims of that patent. Defendants also assert **[**7]** noninfringement of the *'645* and *'909 patents* under the doctrine of equivalents.

1 Precision has not offered noninfringement arguments with respect to the *'909 patent* because, in a letter to the court dated January 19, 1999, Relume stated that it had chosen not to allege any of the claims of its *'909 patent* against Precision. There has been no change in Relume's position since.

For Relume to establish literal infringement, "every limitation set forth in a claim must be found in the accused product or process exactly." *Becton Dickinson and Co. v. C.R. Bard, Inc., 922 F.2d 792, 796 (Fed. Cir. 1990).* Determining literal infringement is a "two-step process." Id. As a first step I must determine the meaning and scope of the claims in dispute: a step "more commonly known as claim construction." *Markman v. Westview Instruments, Inc., 52 F.3d 967, 976 (Fed. Cir. 1995).* The second step requires me to compare the construed claims with the product or process accused of infringement. **[**8]** Id. The first step is a question of law, see *id. at 979*, while the second step is a question of fact, see *North American Vaccine v. American Cyanamid Co., 7 F.3d 1571, 1574 (Fed. Cir. 1993).*

When construing a claim under the first step, I must consider the intrinsic evidence of record: the claim language, the specification, **[*793]** and, if produced, the prosecution history. See *Markman, 52 F.3d at 979.* "The appropriate starting point, however, is always with the language of the asserted claim itself." *Phonometrics, Inc. v. Northern Telecom, Inc., 133 F.3d 1459, 1464 (Fed. Cir. 1998).* This is so because "the language of the claims . . . defines the bounds of the patentee's exclusive rights." *Wiener v. NEC Electronics, Inc., 102 F.3d 534, 539 (Fed. Cir. 1996).*

In construing the claim language at issue, I am guided by the principle that "claim language is interpreted to ascertain the meaning that a person of ordinary skill in the art would give to the claims in dispute." *Schering Corp. v. Amgen, Inc., 18 F. Supp. 2d 372, 380 (D. Del. 1998)* (citing *Wiener, 102 F.3d at 539*). **[**9]** Although words in a claim generally have their ordinary meaning, "a patentee may choose to be his own lexicographer and use terms in a manner other than their ordinary meaning, as long as the special definition of the term is clearly stated in the patent specification or file history." *Vitronics Corp. v. Conceptronic, Inc., 90 F.3d 1576, 1582 (Fed. Cir. 1996).* Even when a patentee does not give a word a special meaning, the specification still "acts as a dictionary when it expressly defines terms used in the claims or when it defines terms by implication." Id. As such, the specification is often "the single best guide to the meaning of a disputed term." Id.

If the intrinsic evidence does not resolve the ambiguities of disputed claim language, I may then consider extrinsic evidence, such as expert testimony regarding how those skilled in the art would interpret the disputed claim. See *id. at 1583.* While extrinsic evidence may be used "as an aid in arriving at the proper construction of the claim," it "may not be used to vary or contradict the otherwise unambiguous meaning of the claim." *Desper Products, Inc. v. QSound Labs., Inc., 157 F.3d 1325, 1333 (Fed. Cir. 1998).* **[**10]** In most cases, intrinsic evidence will suffice to resolve ambiguity, and so, in those cases, consideration of the extrinsic evidence for construction purposes would be "improper." See *Vitronics, 90 F.3d at 1583.*

Based on the record before me, I am satisfied that I can "independently assess the claims, the specification, and if necessary the prosecution history, and relevant extrinsic evidence, and declare the meaning of the claims." *Exxon Chemical Patents, Inc. v. Lubrizol Corp., 64 F.3d 1553, 1556 (Fed. Cir. 1995).* The claims I interpret are those the parties have debated with respect to their meaning and scope.. I will not refer to any prosecution history because no party has placed it in issue. I emphasize that my Markman construction of the disputed claims serves only to determine the meaning a person of ordinary skill in the art would give to those claims. See *Wiener, 102 F.3d at 539.*

IV. Claim Construction

A. The *'645 Patent*

Relume's *'645 patent* describes an apparatus for supplying regulated voltage d.c. electrical power to an LED array. The patent has twenty-three claims, but only claims 1, 2, 4, 5, and [**11] 6 are at issue in the parties' summary judgment motions. These five claims read as follows:

> 1. An apparatus for supplying regulated voltage d.c. electrical power to an LED array comprising:
>
> a rectifier means (32) having an input and an output, said rectifier means (32) being responsive to a.c. power at said input for generating rectified d.c. power at said output;
>
> a power factor correction converter means (38) having an input connected to said output of said rectifier means (32) and an output, said power factor correction converter means (38) being responsive to said rectified d.c. power at said power factor correction converter means input for generating regulated voltage d.c. power at said power factor correction converter means output; and
>
> an LED array (12) having an input connected to said output of said power factor [*794] correction converter means (38) for receiving said regulated voltage d.c. power to illuminate said LED array (12).
>
> 2. The apparatus according to claim 1 wherein said power factor correction converter means (38) is a power factor correcting and voltage regulating buck/boost switchmode converter.
>
> * * *
>
> 4. The apparatus according to claim 1 [**12] including an electromagnetic interference filter means (28) connected to said input of said rectifier means (32) for preventing conducted interference from feeding back onto a.c. power lines (22) connected to said rectifier means input.
>
> 5. The apparatus according to claim 1 including an adaptive clamp circuit means (24) connected to said input of said rectifier means (32) for eliminating leakage current problems.
>
> 6. The apparatus according to claim 5 wherein said adaptive clamp circuit means (24) has an input adapted to be connected to a pair of a.c. power lines (22), a pair of clamp circuit output lines (26) connected to said adaptive clamp circuit means input, a voltage sensing means (48) connected across said input of said adaptive clamp circuit means (24), and a controlled load means (50) connected across said clamp circuit output lines (26) and to said voltage sensing means (48), said voltage sensing means (48) being responsive to a magnitude of a.c. voltage at said adaptive clamp circuit means input lower than a predetermined magnitude for turning on said controlled load means (50) to connect a low impedance load (60) in said controlled load means (50) across said clamp [**13] circuit output lines (26) and said voltage sensing means (48) being responsive to a magnitude of the a.c. voltage at said adaptive clamp circuit means input equal to or greater than said predetermined magnitude for turning off said controlled load means (50) to disconnect said low impedance load (60) from said clamp circuit output lines (26).

'645, 13:16 to 14:18. [2]

2 My citations to the *'645* and *'909 patents* will

be in the form of "patent, column: lines."

1. Claim 1

a. "LED array"

The parties' dispute over claim 1's "LED array" concerns its configuration and components. Ecolux, Dialight, and Precision argue that the "LED array" requires a series-parallel configuration of strings of LEDs with a ballast resistor [3] in each string. Lumileds supports this construction, but also argues that if I reject it, the plain meaning of "LED array" requires only a group of LEDs forming a complete unit - a broad construction that could encompass a single string of LEDs in series or a series-parallel configuration. **[**14]** Relume contends that the "LED array" requires a series-parallel configuration, but not ballast resistors.

3 A ballast resistor is a resistor that limits and spreads current across a load (here the LED array). This "ballasting" function gives the resistor its name.

The parties' proposed constructions all draw on the specification of the *'645 patent* for primary support. [4] Ecolux, Dialight, and Precision find their construction of "LED array" in a specification passage that describes the array's preferred embodiment: "The LED array 12 includes a plurality of strings of series connected LEDs 14 with a ballasting resistor 16 (R1, R2, R3, R4, R5,...) connected in each string." '645, 5:5-8. Figure 5 of the patent diagrams this preferred embodiment of the array. Numeral 12 of Figure 5 labels the LED array as all components to the right of a vertical dash line. It also refers to **[*795]** the specification passage relied on by the defendants and to the phrase "LED array" in the language of claim 1.

4 The exception is the alternative, plain meaning construction offered by Lumileds.

[15]** Relume finds its proposed construction in a different passage of the specification than do defendants. That passage describes the preferred embodiment of the LED array as "consisting of a large number of series-parallel connected LED devices." '645, 6:24-25. Relume also relies on the patent's diagrams of three prior art LED arrays, all of which depict series-parallel configurations, but only one of which depicts ballast resistors. From these references - the preferred embodiment passage and the prior art diagrams - Relume argues that a person of ordinary skill in the art of LED array power supplies would understand the series-parallel configuration, but not the ballast resistors, to be a necessary part of the claimed "LED array".

My construction of "LED array" must begin with the language of claim 1. See *Phillips Petroleum Co. v. Huntsman Polymers Corp., 157 F.3d 866, 871 (Fed. Cir. 1998).* It does not mention series-parallel LED configurations or ballast resistors. All that claim 1 explicitly requires the "LED array" element to have as physical structure is 1) the LEDs in an array arrangement and 2) an input connected to the output of the power factor correction **[**16]** converter means.

In fact, claim 1 speaks broadly of its claimed invention. It states at the outset that it covers "an apparatus for supplying regulated voltage d.c. electrical power to an LED array." '645, 13:16-17. It further states that this apparatus has three major elements: a rectifier means, a power factor correction converter means, and an LED array. Thus, upon reading claim 1 in its entirety, a person of ordinary skill in this art would understand that it covers a certain kind of regulated voltage power supply for an LED array, but would not necessarily conclude that the invention's application was restricted solely to traffic signals. To put it another way, the invention described by the language of claim 1 is a relatively simple one with potentially broad application: any conceivable use for regulated voltage LED illumination.

This point is important because it informs the ordinary meaning of the phrase "LED array." By itself, the word "array" connotes nothing more than a series or orderly grouping of things. Webster's Third New International Dictionary (1986) (hereafter "Webster's") defines it variously as "a regular and imposing grouping or arrangement" and "an **[**17]** impressive list, series, or group of things." [5] The modifier "LED" simply tells the reader that the things arranged by the array are LEDs. Together, then, the words "LED" and "array" have a range of ordinary meaning that can cover LED configurations as simple as a string of LEDs in a series or as complicated as the series-parallel LED strings of the *'645 patent*'s preferred embodiment. The entirety of claim 1 does not alter this range of ordinary **[*796]** meaning. [6] Thus, after reading claim 1, a person of ordinary skill in the art of LED array power supplies would understand the phrase "LED array," on its face, to cover a wide scope

of LED configurations, including, but not limited to, the simple series and the series-parallel.

5 Relume argues, without reference to a dictionary or treatise, that "array" merely means "array shaped," "having a two dimensional extent, width and height." (Pl.'s Consolidated Opp. at 12.) I reject this definition. Besides being circular and at odds with Webster's, it is critically incomplete. It does not speak to the ordered nature of arranged things that the word array evokes. It is also fails to gain Relume what it wants for validity purposes: a construction of "LED array" that excludes from its scope a single string of LEDs in a series. That simple configuration does have a width and a height: it is one LED wide and however many LEDs high.

A related point: In its response to Lumileds' anticipation motion, Relume raised arguments vehemently attacking the use of dictionaries in claim construction because they are extrinsic evidence. (See Pl.'s Anticipation Opp. Mot. at 9.) Throughout my opinion, I follow the rule laid down in Vitronics, which permits me to consult dictionaries and treatises "at any time" in my claim construction so long as the dictionary's definition does not contradict the definition supplied by the intrinsic evidence of the patent. See *90 F.3d at 1584, n.6.*

[**18]

6 Some defendants suggest that the reference numeral attached to "LED array" limits the phrase's ordinary meaning by referring the reader to the diagram of the array's preferred embodiment, which shows ballast resistors in the array. I find this argument unpersuasive, however. A reference numeral is simply a convenient tool for directing the reader to an example of the element the patentee has claimed. Had the drafter wanted to incorporate the limitations of the preferred embodiment into the language of claim 1, he or she could have done so quite easily with words.

The parties' proposed constructions for "LED array" raise the issue whether the specification narrows the phrase's ordinary meaning. According to the United States Court of Appeals for the Federal Circuit ("Federal Circuit"), I "must presume that the terms in a claim mean what they say, and, unless otherwise compelled, give fall effect to the ordinary and accustomed meaning of claim terms." *Johnson Worldwide Assocs., Inc. v. Zebco Corp., 175 F.3d 985, 989 (Fed. Cir. 1999).* The Federal Circuit has identified "two situations [**19] where a sufficient reason exists to require the entry of a definition of a claim term other than its ordinary and accustomed meaning." *Id. at 990.* "The first arises if the patentee has chosen to be his or her own lexicographer by clearly setting forth an explicit definition for a claim term." Id. "The second is where the term or terms chosen by the patentee so deprive the claim of clarity that there is no means by which the scope of the claim may be ascertained from the language used." Id. This second situation is not at issue here because, as I have explained, the phrase "LED array" is clear on its face.

The ballast resistor construction of "LED array" proposed by defendants is essentially an argument under the first situation. That is, defendants believe that the drafter of the *'645 patent* acted as his/her own lexicographer and clearly set forth an explicit definition of "LED array" in the specification that requires ballast resistors. At a March 22, 1999 hearing, I stated an inclination for a preliminary construction of "LED array" that was consistent with defendants' construction.

After further consideration, however, I am not persuaded that I should [**20] adopt their construction, which relies entirely on a passage and a diagram that describe the preferred embodiment of claim 1's LED array. It is a fundamental rule of claim construction that "references to a preferred embodiment, such as those often present in a specification, are not claim limitations." *Laitram Corp. v. Cambridge Wire Cloth Co., 863 F.2d 855, 865 (Fed. Cir. 1988)*; see also *Ekchian v. Home Depot, Inc., 104 F.3d 1299, 1302-03 (Fed. Cir. 1997).* Otherwise, "there would be no need for the claims." *SRI Int'l v. Matsushita Elec. Corp. of America, 775 F.2d 1107, 1121 (Fed. Cir. 1985).*

Claim 1 only requires its array to incorporate one component: the LEDs. No additional components are therefore necessary. Except for its description of the preferred embodiment of the array, the specification of the *'645 patent* teaches nothing different. Its statement of the invention's objectives does not mention ballast resistors or claim any functional advantage related to ballast resistors. Perhaps most telling, the preferred embodiment passage relied on by defendants is itself only

cursory in its reference to ballast resistors; it does [**21] not explain what advantage is to be gained by using them in the array. From the context of the *'645 patent*, then, it is clear that the drafter did not intend for the preferred embodiment's use of ballast resistors to limit the full range of ordinary meaning inherent in the "LED array" phrase of claim 1.

Precision attempts to justify a ballast resistors requirement on functional [*797] grounds. As this argument goes, a person of ordinary skill in the art would understand ballast resistors to be necessary components in any voltage-regulated LED array because, without them, a voltage-regulated LED array will not illuminate well in all conditions. From an engineering standpoint, ballast resistors undoubtedly improve the performance of a voltage-regulated LED array. By limiting and spreading the current in the array, they help the LEDs maintain a more even level of illumination. Yet claim 1 recites no limitations on the array's illumination level, nor does it recite limitations for limiting and spreading current. Because their function is not essential to the claimed array, it follows that ballast resistors themselves are not essential components for that array.

Having determined that the "LED [**22] array" of claim 1 does not require ballast resistors, the question then becomes whether it also requires a certain configuration of the LEDs. Relume essentially argues that the "LED array" of claim 1 requires a series-parallel configuration of LEDs, but not necessarily the exact series-parallel example of the patent's preferred embodiment. Defendants argue that this construction improperly imports limitations from the specification into claim 1. They correctly point out the fundamental inconsistency in Relume's objection to a ballast resistors requirement, which comes from the specification, and its support for a series-parallel requirement, which also comes from the specification. Relume responds by contending that a person of ordinary skill in the art would know that a series-parallel configuration is necessary because LED string redundancy allows the array to continue to emit light in the event of a single point LED failure. [7]

7 A single point LED failure occurs when one LED in a string of connected LEDs fails, for whatever reason, to conduct electrical current and therefore emit light. This failure causes the entire LED string to fail as well. A series-parallel configuration of LED strings minimizes the impact of a single point LED failure because, even if one string is extinguished, the other strings will continue to emit light.

[**23] I find Relume's series-parallel construction of "LED array" unpersuasive, however, because it fails to overcome the presumption in favor of the phrase's ordinary and accustomed meaning. The language of claim 1 does not explicitly limit the "LED array" to a series-parallel configuration. Nor does it implicitly do so. As discussed above, the phrase "LED array" means on its face that the claimed element must arrange LEDs in a regular grouping. A series configuration is simply the logical minimum of this facial meaning and thus cannot be excluded from the phrase's scope. The specification supports this conclusion. It notes that both series and series-parallel configurations exist in the prior art as design choices for LED arrays. '645, 1:18-30.

If I were to determine that a person of ordinary skill in the art would read a series-parallel limitation into "LED array," I would violate the fundamental principle that the preferred embodiment not limit the meaning of the claims. See *Laitram, 863 F.2d at 865*. The specification does not indicate that the drafter acted as his own lexicographer and intended for the series-parallel definition of the preferred embodiment to override [**24] the ordinary meaning of "LED array." See *Zebco, 175 F.3d at 990*. Aside from the preferred embodiment, there are no explicit series-parallel definitions for claim 1's LED array set forth in the specification. The specification also does not mention a series-parallel configuration in its summary of the invention, nor in its statement of the invention's objectives. Finally, the specification's diagrams of the prior art tellingly attach "series-parallel" as an adjective to "LED array"; this further reveals that the phrase "LED array" does not inherently teach a series-parallel configuration to those in the art.

Relume falls back on a functionality argument to support its narrow construction. [*798] It contends that the LED array of claim 1 requires, at minimum, a series-parallel configuration in order to gain the benefit of LED string redundancy. But just as Precision's function argument failed, so too does Relume's. Claim 1 nowhere recites a limitation on the configuration of the LED array, nor does it state a functional advantage from a series-parallel configuration. Moreover, claim 1 states no concern for how well or how safely the LED array

illuminates, only that it does. [**25] All of this makes sense given that the invention described by claim 1 is not a kind of LED array or a safer LED array, but an apparatus that supplies voltage-regulated electrical power to any kind of LED array, whatever its application.

I conclude that the intrinsic evidence of record would lead a person of ordinary skill in the art of LED array power supplies to understand the "LED array" of claim 1 to mean an orderly arrangement of LEDs - a meaning that encompasses both a simple series and a series-parallel configuration. I further conclude that a person of ordinary skill in this art would not understand the "LED array" of claim 1 to require ballast resistors.

b. "power factor correction converter means"

Lumileds argues that *35 U.S.C. § 112*, P 6 governs the construction of claim 1's "power factor correction converter means" and limits it in scope to the corresponding structure disclosed in the specification: a switchmode buck/boost converter and a commercially available power factor controller. Relume argues that *35 U.S.C. section 112*, paragraph 6 does not apply because the language "power factor correction converter" implicitly recites sufficient structure [**26] to one of ordinary skill in the art of LED array power supplies.

Claim 1 describes the "power factor correction converter means" as

> having an input connected to said output of said rectifier means (32) and an output, said power factor correction converter means (38) being responsive to said rectified d.c. power at said power factor correction converter means input for generating regulated voltage d.c. power at said power factor correction converter means output.

'645, 13:22-28. By associating the word "means" with two functions - power factor correction [8] and voltage regulation - claim 1 uses express means-plus-function language to describe the "power factor correction converter means" element. This creates a presumption that the "power factor correction converter means" is a means-plus-function element governed by *35 U.S.C. section 112*, paragraph 6. See *Al-Site Corp. v. VSI Int'l, Inc., 174 F.3d 1308, 1318 (Fed. Cir. 1999)* ("if the word "means" appears in a claim element in combination with a function, it is presumed to be a means-plus-function element to which *35 U.S.C. § 112*, P 6 applies").

> 8 The *'645 patent* explains that "power factor (p.f.) is well understood in the electrical engineering community as the ratio of real power to real power plus reactive power." '645,2:10-12. The closer a device's power factor ratio is to one, the better its efficiency. Poor power factor typically results when voltage and current are out of phase, but it can also result from harmonic distortion.

[**27] Relume contends that claim 1 overcomes this presumption by reciting sufficient structure. Relume specifically argues that a person of ordinary skill in the art would understand a "power factor correction converter" to be "a switching power supply that has some control feature to improve diode conduction time and increase power factor and reduce distortion." (Pl.'s Consolidated Opp. at 22.) Relume also notes that the claim language recites a location for the "power factor correction converter means" in the invention - between the rectifier and the LED array - and describes it as having an input and an output. (See id.)

[*799] The Federal Circuit has determined that a presumption of *35 U.S.C. section 112*, paragraph 6 governance "can be rebutted if the evidence intrinsic to the patent and any relevant extrinsic evidence so warrant." *Personalized Media v. Int'l Trade Comm'n, 161 F.3d 696, 704 (Fed. Cir. 1998)*. Throughout the rebuttal inquiry, "the focus remains on whether the claim as properly construed recites sufficiently definite structure to avoid the ambit of *35 U.S.C. § 112*, P 6." Id. A claim recites sufficient structure when it elaborates the structure, material, or acts necessary [**28] to perform entirely the recited function. See *Sage Products, Inc. v. Devon Industries, Inc., 126 F.3d 1420, 1427-28 (Fed. Cir. 1997)*.

Close scrutiny of the term "power factor correction converter means" reveals that it implicitly elaborates sufficient structure to a person of ordinary skill in the art of power supplies. The structural device claimed is a "converter means," and its functions are "power factor correction" and "being responsive to said rectified d.c. power...for generating regulated voltage d.c. power." [9] Although perhaps unremarkable to the layperson, the word "converter" is a structurally meaningful term-of-art to those of ordinary skill in the art of power supply

electronics. According to Marty Brown's Power Supply Cookbook (1994), it connotes the generic structure of a switching power supply: that is, a switch and its controller circuit. [10] See id. at 25-26. The Power Supply Cookbook also makes it clear that power factor correction and voltage regulation are typical functions for a switching power supply to perform. See id. Thus claim 1's association of "converter means" with its specified functions of power factor correction and [**29] voltage regulation would reinforce the structural connotations of "converter" to one of ordinary skill in this art.

9 Identification of the "power factor correction" function is less obvious than the voltage regulation function because the qualifier "power factor correction" is not phrased in the "means...for" format that usually specifies a function in claim language. The "means...for" formality, however, need not be present for me to interpret "power factor correction" as an additional functional constraint on the "converter means." See *Personalized, 161 F.3d at 705* (finding that the adjective "digital" functionally constrained the word "detector" even without "means...for" language).

10 The Power Supply Cookbook is an authoritative instructional design text for engineers in the field of power supply electronics. The background section of the *'645 patent* cites it as relevant prior art. Thus I consider it to be evidence intrinsic to the *'645 patent* and properly considered in my Markman construction of the claim term "converter." See *Markman, 52 F.3d at 979.*

[**30] I conclude that the implicitly sufficient level of structural elaboration in the term "converter" removes the "power factor correction converter means" from its presumed statutory category as a means-plus-function element governed by *35 U.S.C. section 112*, paragraph 6. See *Personalized, 161 F.3d at 705* (holding that the term "detector," even though it does not "specifically evoke a particular structure," nevertheless elaborates sufficient structure because it conveys "to one knowledgeable in the art a variety of structures known as 'detectors'"); see also *Cole v. Kimberly-Clark Corp., 102 F.3d 524, 531-32 (Fed. Cir. 1996)* (affirming a district court's conclusion that the "perforation means" did not fall under *35 U.S.C. section 112*, paragraph 6 because the ordinary meaning of the term "perforation" recites sufficient structure to one of ordinary skill in the relevant art). Accordingly, I hold that a person of ordinary skill in the art of LED array power supplies would understand claim 1's "power factor correction converter means" to require the structure of a switching power supply.

c. "generating regulated voltage

Defendants argue that the plain meaning of "generating [**31] regulated voltage" excludes from the scope of claim 1 those power supplies designed to regulate current. Relume argues that because of the basic electrical principle of Ohm's Law [*800] (voltage = current x resistance) current regulation will result in voltage regulation in a certain circumstance - specifically when resistance is constant. Relume argues that the voltage regulation performed by its invention is limited to that circumstance and, therefore, devices designed to regulate current can fall within the scope of its invention.

I begin my claim construction with the ordinary meaning of the disputed phrase. See *Phillips, 157 F.3d at 871.* The basic meaning of "generate" found in Webster's is that of a thing producing something else. [11] The meaning of "regulated" is likewise straightforward; Webster's conveys the idea of something being ordered and controlled. [12] Finally, Webster's defines "voltage" as "electric potential or potential difference expressed in volts."

11 Webster's most pertinent definitions of "generate" are 1) "to cause to be: to bring into existence," 2) "to originate (something material) by a physical or chemical process," and 3) "to be the cause of (a state of mind, an action, or something immaterial or intangible)."

[**32]

12 Webster's most pertinent definitions of "regulate" are 1) "to reduce to order, method, or uniformity" and 2) "to fix the time, amount, degree, or rate of."

By combining these dictionary definitions, it is clear that "generating regulated voltage" means, on its face, the function of producing controlled electric potential. This function has a specialized understanding to those in the field of electronics. According to The Illustrated Dictionary of Electronics (7th ed. 1997), "voltage regulation" is "the stabilization of a voltage against fluctuations in source or load." [13] Thus, upon reading the words "regulated voltage," a person of ordinary skill in

the art would understand claim 1 to require the "power factor correction converter means" to stabilize the voltage it generates against fluctuations either in the input line voltage (the source) or in the LED array (the load).

13 Relume is correct to point out the significance of the "or" in this definition of "voltage regulation." A device need not regulate voltage against fluctuations in both source *and* load to be called voltage regulating in the art. The specification of the *'645 patent* makes it clear that claim 1's "converter means" is a voltage regulator concerned only with minimizing source voltage fluctuations.

[**33] Yet that is not all the language of claim 1 communicates regarding its voltage regulation function. As held above, the ordinary meaning of "converter" also implies to one of ordinary skill in the art the structure necessary to perform voltage regulation: a switching power supply. At its most basic, a switching power supply must have some sort of switch and a controller circuit. See Power Supply Cookbook at 25-26. For a voltage-regulating power supply, the controller circuit's "main purpose" must be "to maintain a regulated output voltage." Id. at 26. It does so by acting as a voltage feedback loop. See id. at 73.

These structural limitations implied by the ordinary meaning of "converter" cannot be ignored. Voltage regulation calls for unique componentry - for example, the controller's output voltage feedback loop. Yet there is an even more important point: a voltage-regulating power supply is a device expressly designed to stabilize the electrical property of voltage and thus generate regulated voltage. It is built to act on voltage, not current.

Relume's tortured construction of "generating regulated voltage" turns a blind eye to these realities. Relume wants claim [**34] 1 to be nonsensically construed so that any device, regardless of its design and structure, would fall within its scope so long as that device effects source voltage regulation in the limited circumstance when resistance is constant. I have a duty, however, to give meaning to all the words in claim 1 in order to determine the scope of its claimed invention; the drafter has linked the "converter means" to the "generating regulated voltage" function. Thus [*801] I cannot ignore the implicit structural limitations in the term "converter" - structural limitations, I note, that Relume urged me to recognize in order to avoid the application of *35 U.S.C. section 112*, paragraph 6 to the "converter means."

There is another flaw in Relume's construction. The much trumpeted truth of Ohm's Law is ultimately immaterial to the resolution of the claim construction question before me. All it tells me is that in a certain situation, when resistance is controlled, current-regulating and voltage-regulating power supplies will have the same effect on their output voltage. It does not tell me anything about the purpose, design, and structure of current-regulating and voltage-regulating devices in the art. Thus, while [**35] interesting, the scientific fact of Ohm's Law does not address the underlying issue posed by the construction of "generating regulated voltage": What does it mean in the art when a converter regulates voltage instead of current?

The specification of the *'645 patent* reinforces these points. In its discussion of prior art power supplies, it recognizes the distinction drawn in the art between current regulation and voltage regulation. [14] That distinction is based on meaningful engineering reasons. For instance, the specification notes that current regulation will result in better LED light output than voltage regulation. '645, 4:51-54. The reason: LED light output is directly related to the current flowing through the LED, not the voltage. There is of course a more obvious basis for the distinction in the art: current regulation and voltage regulation act on, and regulate, different electrical properties. Thus it is clear that treating power supplies designed for current regulation like those designed for voltage regulation - the effect of Relume's construction - would violate precepts in the art.

14 So too does The Illustrated Dictionary of Electronics. It gives distinct definitions for voltage regulation (quoted above) and for current regulation ("the stabilization of current at a predetermined level or value").

[**36] There is nothing in the specification that alters my analysis of "generating regulated voltage." See *Zebco, 175 F.3d at 990*. It discloses a voltage-regulating switching power supply for the patent's invention that is structurally consistent with the ordinary meanings of "converter" and "generating regulated voltage" I discuss above:

> The converter 38 includes a power factor correction (P.F.C.) integrated circuit (I.C.)

> controller 40, which is a commercial device available from many sources and functions by allowing current to charge a storage capacitor C (LARGE) only in phase with the rectified a.c. voltage thereby assuring a power factor close to unity. The control I.C. 40 also provides voltage regulation in the switchmode buck/boost converter by monitoring the output voltage and adjusting the high frequency on-off switching period of the pass element commensurately.

'645, 5:41-53. Not surprisingly, the specification nowhere instructs the reader on how a current-regulating power supply could be used instead of a voltage-regulating power supply to effect the aims of the invention.

For all of the reasons discussed, then, I hold that a person of ordinary [**37] skill in the art of LED array power supplies would understand "generating regulated voltage" to mean that claim 1's "converter means" is designed to produce stabilized voltage at its output despite fluctuations in its input voltage. Because the intrinsic evidence of the patent provides a clear meaning for "generating regulated voltage," I decline to consider the extrinsic testimony of the *'645 patent*'s inventor, Mr. Hochstein, which Relume offers in support of its construction. See *Southwall Tech., Inc. v. Cardinal IG Co., 54 F.3d 1570, 1578 (Fed. Cir. 1995)*; see also *Vitronics, 90 F.3d at 1583*.

2. Claim 2

The parties do not dispute the meaning of claim 2. As a dependent claim to claim 1, [*802] it incorporates all the limitations of claim 1, but with one exception. Instead of a generic "converter means," it teaches the use of a specific type: "a power factor correcting and voltage regulating buck/boost switchmode converter." '645, 13:33-36.

3. Claim 4

The parties do not dispute the meaning of claim 4. Like claim 2, it is a dependent claim to claim 1. It therefore incorporates all the limitations of claim 1 and adds another: the use of an [**38] "electromagnetic interference filter means." '645, 13:43. It also requires that the filter be located before the rectifier means. '645, 13:42-46.

4. Claim 5

This claim recites an adaptive clamp circuit means for eliminating leakage current problems. [15] '645, 13:47-50. Defendants contend that it is written in "means-plus-function" format and is therefore governed by *35 U.S.C. § 112*, P 6. Relume does not appear to dispute defendants' proposed construction.

> 15 Leakage current creates problems for traffic signals because it falsely triggers the conflict monitors at an intersection. Conflict monitors exist to detect and prevent two green lights in perpendicular directions. A falsely triggered conflict monitor tells the intersection's traffic lights to go to blinking red signals when there is no need.

I agree with defendants' construction. By associating the word "means" with the function of eliminating leakage current problems, claim 5 uses express means-plus-function language to describe [**39] its "adaptive clamp circuit means" element. This creates a presumption that the "adaptive clamp circuit means" is a means-plus-function element governed by *35 U.S.C. section 112*, paragraph 6. See *Al-Site, 174 F.3d at 1318*. Unlike the dispute over the "power factor correction converter means," however, Relume has not argued that claim 5 overcomes this presumption by reciting sufficient structure. Even if Relume were to argue that point, my review of the language of claim 5 does not reveal that it elaborates sufficient structure necessary to perform entirely the recited function. See *Sage Products, 126 F.3d at 1427-28*.

Thus according to *35 U.S.C. section 112*, paragraph 6, the "adaptive clamp circuit means" of claim 5 is to be construed "to cover the corresponding structure, material, or acts described in the specification and equivalents thereof." *35 U.S.C. § 112*, P 6; see also *Lockwood v. American Airlines, Inc., 107 F.3d 1565, 1570-71 (Fed. Cir. 1997)*. Accordingly, I hold that a person of ordinary skill in the art would understand the corresponding structure described in the specification of the *'645 patent* to be a voltage sensing [**40] means (48) comprised of a transistor (Q1) and a Zener diode (D5) and a controlled load means (50) comprised of a transistor (Q2) and a resistor (60). '645, 7:40 to 8:3. The specification explains their operation thus:

> The clamping circuit 24 works by using the sensing transistor Q1 and the Zener diode D5 (the voltage sensing means 48 of FIG. 6a) to determine if the line voltage is below a certain magnitude (typically 40 volts)....If the Zener diode D5 does not conduct, the transistor Q2 is turned on to place the load resistor 60 [across] the power lines 22 causing the leakage voltage to drop below 10 volts. The transistor Q2 and the resistor 60 are the controlled load means 50 of FIG. 6a. Whenever the traffic signal controller relay "closes", the line voltage appearing at the input to the adaptive clamping circuit 24 rises to nominally 120 volts and the sensing circuit (Q1 and D5) turn off the controlling transistor Q2, removing the resistor 60 from the circuit thereby preventing unnecessary dissipation of power.

'645, 7:53 to 8:1.

5. Claim 6

Claim 6, which depends from claim 5, merely recites the specific structure presented [*803] in the specification. Accordingly, [**41] claim 6 is similar if not identical in scope to claim 5, in spite of the doctrine of claim differentiation. See *Laitram Corp. v. Rexnord, Inc., 939 F.2d 1533, 1538 (Fed. Cir. 1991)* (finding that the doctrine of "claim differentiation" cannot override *section 112*, paragraph 6).

B. The *'909 Patent*

Relume's *'909 patent* describes an apparatus, as well as a method, that maintains the luminous intensity of an LED. The patent has 18 claims. Claims 1-3, 6, 7, 9-12, 15, 16, and 18 are at issue in the parties' motions. They read as follows:

> 1. A circuit for maintaining the luminous output of a light emitting diode, said circuit comprising:
>
> > at least one light emitting diode (LED) (12) for producing a luminous output;
> >
> > a sensor (22, 24) for sensing a condition proportional to said luminous output of said LED (12) and for producing a luminous output signal;
> >
> > a power supply (16) electrically connected to said LED (12) for supplying ON/OFF pulses of electrical energy to produce the luminous output of said LED (12); and
> >
> > said power supply (16) including a switching device responsive to said luminous output signal for adjusting the electrical energy supplied by [**42] said pulses per unit of time to adjust the average of said current passing through said LED (12) to maintain the luminous output of said LED (12) at a predetermined level.
>
> 2. A circuit as set forth in claim 1 wherein said sensor (22) includes means for sensing changes in temperature of said LED (12).
>
> 3. A circuit as set forth in claim 2 wherein said sensor (22) includes a predetermined temperature behavior model to establish the increase in said current passing through said LED (12) as a function of the operating temperature of said LED (12) integrated with said predetermined temperature behavior model.
>
> * * *

6. A circuit as set forth in claim 1 wherein said switching device includes means for adjusting the electrical energy supplied by said pulses per unit of time by adjusting the frequency of said pulses.

7. A circuit as set forth in claim 1 wherein said switching device includes means for adjusting the electrical energy supplied by said pulses per unit of time by adjusting the width of said pulses.

* * *

9. A circuit as set forth in claim 1 including a filter for filtering the electrical energy supplied by said pulses into substantially d.c. supplied **[**43]** to said LED for producing said luminous output.

10. A method of maintaining the luminous output of a light emitting diode (LED) comprising the steps of:

> supplying ON/OFF pulses of electrical energy from an adjustable power supply (16) for establishing electrical current passing through the LED (12);
>
> sensing (22, 24) a condition proportional to the luminous output of the LED (12); and
>
> adjusting the electrical energy supplied by the ON pulses per unit of time to adjust the average of the current passing through the LED (12) to maintain the luminous output of the LED (12) at a predetermined level.

11. A method as set forth in claim 10 wherein sensing a condition is further defined as sensing changes in temperature of the LED (12).

12. A method as set forth in claim 10 further defined as establishing a predetermined **[*804]** temperature behavior model and increasing the current passing through the LED (12) as a function of the operating temperature of the LED (12) integrated with the predetermined temperature behavior model.

* * *

15. A method as set forth in claim 10 further defined as adjusting the electrical energy supplied by said pulses per unit of time by adjusting **[**44]** the frequency of said pulses.

16. A method as set forth in claim 10 further defined as adjusting the electrical energy supplied by said pulses per unit of time by adjusting the width of said pulses.

* * *

18. A method as set forth in claim 10 including filtering the output of the power supply for filtering the electrical energy supplied by said pulses into substantially d.c. supplied to the LED for producing said luminous output.

'909, 6:64-67, 7:all, and 8:all.

1. Claim 1

a. "condition proportional"

Ecolux construes "condition proportional" to mean directly proportional or having "the same or constant ratio." Ecolux believes this construction requires the invention's temperature sensor [16] to be located on the LED circuit board, as opposed to somewhere else in the invention's circuitry. Relume argues that this locational requirement is an unnecessary limitation on the claimed invention. Relume believes that the scope of "condition proportional" includes temperature sensors that are sensitive to the ambient temperature surrounding the LEDs.

16 The *'909 patent* discloses two kinds of preferred embodiment sensors: a light sensor and

a temperature sensor. Ecolux focuses its construction arguments on the temperature sensor because that is the kind of sensor its accused product uses.

[**45] Claim 1 does not recite a limitation on the location of its sensor. It describes the "sensor" as performing two functions: "sensing a condition proportional to said luminous output of said LED (12) and...producing a luminous output signal." '909, 7:1-3. This language limits the possible universe of conditions that could be sensed by the sensor to those that have a "proportional" relationship to the light output of the LEDs. [17] Webster's most relevant definition of "proportional" is "having the same or a constant ratio;" this is, in fact, Ecolux's proposed definition. [18] The key to understanding its scope is in the meaning of "ratio." Webster's defines it as "the fixed or approximate relation of one thing to another." Therefore all that claim 1 requires its sensor to do is sense a condition that has a "fixed relation" to the light emitted from the LEDs; this function does not imply a locational requirement for the invention's temperature sensor.

17 A related point regarding the "condition" sensed: the claim language does not limit it to the temperature of the LEDs as Ecolux has also argued. It is worth repeating that the only limit on the "condition" sensed is whether it is "proportional to the luminous output of the LEDs."

[**46]

18 Ecolux's definition comes from its expert, Barry N. Feinberg. (See Ecolux's Mem. in Support of Mot. for Summ. J. of Non-Infringement at 7 & Ex. D.) He states without explanation that it is the definition given to "proportional" by those in engineering and mathematics. (See id.) To the extent that I accept "having the same or a constant ratio" as the definition of "proportional," I do so because it is the ordinary meaning of the word (as indicated in Webster's) and not because it is the opinion of Feinberg. Furthermore, in adopting this definition, I do not also adopt the alternative, "direct proportion" definition proposed by Ecolux. The claim language uses "proportional" without any qualification.

Despite the fact that the language of claim 1 neither explicitly or implicitly recites a location for the sensor, Ecolux nevertheless argues that such a requirement exists because the preferred embodiment [*805] diagram of the temperature sensor depicts it on the LED circuit board. Aside from this diagram, I find no support in the patent's specification for a locational requirement. Ecolux's [**47] argument is therefore an attempt to restrict claim language that is broader in scope than the preferred embodiment. The rules of claim construction do not permit this. See *Electro Med. Sys. S.A. v. Cooper Life Sciences, 34 F.3d 1048, 1054 (Fed. Cir. 1994)* ("particular embodiments appearing in a specification will not be read into the claims when the claim language is broader than such embodiments").

Accordingly, I hold that a person of ordinary skill in the art of LEDs would understand "condition proportional" to mean that the sensor must sense a condition that has some fixed relationship with the LEDs' light output, but would not understand the phrase to require a certain location for the sensor.

b. "ON/OFF pulses"

On the basis of some of the invention's preferred embodiments, Ecolux argues that the "ON/OFF pulses" of electrical energy called for by claim 1 must have a rectangular wave form. Relume contends that the "ON/OFF pulses" limitation does not require a specific wave form but only that the invention's power supply employ a switching action to control the current delivered to the LEDs.

Ecolux's construction ignores the clear meaning of both the claim [**48] language and the specification. Claim 1 recites no limitation on the shape of the pulses' wave form. Nor does the specification. In fact, it notes that at least two types of wave forms can be utilized by the invention: rectangular and a.c. sinusoidal. Accordingly, I hold that one of ordinary skill in the art of LEDs would understand that "ON/OFF pulses" does not limit the shape of the pulses' wave form but instead requires that a switching power supply create the pulses by turning a switch on and off.

c. "said power supply (16) including a switching device"

Relume contends that this phrase requires the switch to be located in the invention's power supply. Lumileds disagrees, arguing that the word "including" does not

necessarily mean "in."

The ordinary meaning of "including" supports Relume. Webster's defines it as "serving to enclose or cover." Reference to the definition of the verb "include" is also helpful, revealing nuances like "to shut up: CONFINE, ENCLOSE, BOUND," "to place, list, or rate as a part or component of a whole," and "to take in, enfold, or comprise as a discrete or subordinate part." These definitions clearly convey the idea that the power supply of [**49] the *'909 patent* embraces a switch as one of its components. The specification reflects this. By repeatedly describing the power supply as including a switch, it emphasizes to one of ordinary skill in the art that the switch is a part of the power supply.

But there is a more basic point. By having the power supply include a switch, the intrinsic evidence of the *'909 patent* is simply instructing a person of ordinary skill in the art that the power supply of the claimed invention must be a switching power supply. Thus the "including" limitation is less a locational requirement than a componentry requirement. So the specification of the *'909 patent* speaks frequently of the invention's use of "a switch mode power supply." '909, 4:66-67. And it claims a great advantage from the inherent efficiency of such a power supply. '909, 4:50-51. Yet it displays no concern for the location of the switch within the power supply. As the specification states: "It will be appreciated that such a switch mode power supply can take many forms. Within the scope of the present invention, switch mode supplies include any power source 16 that is turned on and off at a frequency consistent with the other operating [**50] [*806] parameters of the system." '909, 4:66 to 5:3.

Accordingly, I hold that a person of ordinary skill in the art would understand "said power supply (16) including a switching device" to mean that the invention of claim 1 requires a switching power supply.

d. "maintain...at a predetermined level"

Lumileds argues that the phrase - "maintain the luminous output of said LED (12) at a predetermined level" - requires claim 1's switching power supply to adjust the current supplied to the LEDs so that their luminous output is essentially constant. Focusing solely on the meaning of the word "predetermined," Relume argues that the disputed phrase requires only that the switching power supply maintain LED light intensity at amounts that are known or modeled in advance.

The drafter's use of the word "maintain" exposes the error of Relume's construction. The idea of uniform or constant output inheres in the word's ordinary meaning. Webster's defines "maintain" as "to keep in a state of repair, efficiency, or validity: preserve from failure or decline." And it defines "predetermine" as "to settle beforehand: settle in advance." Taken together, these definitions establish that the phrase, [**51] "maintain the luminous output of said LED (12) at a predetermined level," simply means to keep the LEDs' luminous output at a level chosen beforehand. [19]

19 Here is what this construction means in practice. Suppose the desired level of LED output chosen beforehand is two units of light. The invention of claim 1 will seek to keep luminous output at this predetermined level of two units despite fluctuations in operating temperature.

The specification does not alter this construction. It states that "the present invention relates to a new method of maintaining an essentially constant luminous output from an LED array, irrespective of operating temperature." '909, 4:42-44. It later observes that either of its contemplated sensors -- the light sensor or the temperature sensor -- "can be used to modulate the average current through the LED array to maintain essentially constant luminous output, irrespective of operating temperature." '909, 5:17-20. It also describes how the invention's preferred embodiment uses a [**52] temperature behavior model "in order to keep the luminous output of the LED array essentially constant at a predetermined level." '909, 3:66-67. Nowhere does the specification indicate that the invention of the *'909 patent* has the ability to produce anything other than essentially constant LED output.

In the end, the clear language of claim 1 and the equally clear specification of the *'909 patent* demonstrate that Relume's construction of "maintain the luminous output of said LED (12) at a predetermined level" is incomplete and at odds with the ordinary meaning of "maintain." It is not enough, as Relume did in its response brief, to offer a definition for "predetermined" and then ignore the more important and relevant meaning of "maintain." The disputed phrase must be examined in its entirety in order to comprehend its full scope.

Accordingly, I hold that a person of ordinary skill in the art would understand the claim language "maintain the luminous output of the said LED (12) at a

predetermined level" to charge the invention of claim 1 with the task of keeping, or preserving from decline, the luminous output of its LEDs at an amount chosen beforehand.

2. Claims 2, 3, 6, 7, and [53] 9**

The parties do not dispute the meaning of these claims, all of which depend from claim 1. Claim 2 requires that the "sensor" recited in claim 1 "include[] means for sensing changes in temperature of said LED (12)." '909, 7:13-15. Claim 3 requires that the temperature feedback system [*807] of the *'909 patent* use a "predetermined temperature behavior model." '909, 7:20-21. Claim 6 specifies that the invention's switching power supply must adjust its ON/OFF pulses "by adjusting the frequency of said pulses." '909, 7:31-32. Claim 7 alternatively teaches a switching power supply that adjusts its ON/OFF pulses "by adjusting the width of said pulses." '909, 7:35-36. Finally, claim 9 requires that the invention of claim 1 include a filter for converting the ON/OFF pulses into d.c. power for the LEDs. '909, 7:41-44.

3. Claim 10

Claim 10 is an independent claim that recites a three-step method for "maintaining the luminous output of a light emitting diode (LED)." '909, 8:1-2. Dialight and Relume dispute the meaning of a phrase -- "adjustable power supply" -- in the claim's first step, which teaches "supplying ON/OFF pulses of electrical energy from an adjustable power supply (16) for [**54] establishing electrical current passing through the LED (12)." '909, 8:3-5. Dialight argues that the disputed phrase requires the use of a switching power supply that adjusts the frequency or pulse width of its ON/OFF current pulses in response to feedback from a sensor. Relume asserts that the "adjustable" limitation only requires a power supply that is adjustable in some broad sense, "e.g., as a voltage regulator." (Pl.'s Consolidated Opp. at 32.)

The ordinary meaning of the adjective "adjustable" provides valuable guidance, though it does not resolve the dispute. Webster's defines the word to mean "capable of being adjusted." Thus to label the invention's power supply as "adjustable" is to say that it is capable of being adjusted. I note that this implies that something acts *on* the power supply to adjust it.

The specification sharpens the reader's understanding of "adjustable" by detailing how the invention's power supply is capable of being adjusted. Thus in summarizing the claimed invention, the specification describes the power supply as including "a switching device responsive to the luminous intensity signal for adjusting the electrical energy supplied by the pulses [**55] per unit of time to adjust the average of the current passing through the LED to maintain the luminous intensity of the LED at a predetermined level." '909, 2:12-17. The specification also later observes that "the primary purpose of the present invention is to increase the average current through the LED array with increasing temperature, by adjusting the pulse width or frequency of LED switch mode power supply." '909, 4:62-65.

These overarching statements about the invention of the *'909 patent* establish that the specification sets forth a specific meaning for "adjustable power supply." See *Zebco, 175 F.3d at 990*. Under that meaning, "adjustable" requires the invention's switching power supply to be responsive to a luminous intensity signal from a sensor so that the ON/OFF current pulses supplied by the power supply can be adjusted in their frequency or pulse width. In other words, the invention's power supply must be capable of being adjusted by the feedback from a sensor that measures, either directly or indirectly, the amount of light emitted by the LEDs.

For these reasons, I reject Relume's construction of "adjustable power supply." Its construction gives a vague [**56] and irrelevant meaning to the phrase that conveniently ignores the specification's description of the patent's invention. The intrinsic evidence of the *'909 patent* gives full support to Dialight's construction of the disputed phrase. I therefore hold that a person of ordinary skill in the art would understand the phrase "adjustable power supply" to mean that the invention's switching power supply must be capable of being adjusted by the luminous intensity signal of a sensor. [20]

20 In support of this construction, Dialight raised additional points regarding the meaning of the third step of claim 10: "adjusting the electrical energy supplied by the ON pulses per unit of time to adjust the average of the current passing through the LED (12) to maintain the luminous output of the LED (12) at a predetermined level." In particular, Dialight argued that *35 U.S.C. § 112*, P 6 governed that step as a "step-plus-function" element and thus that the

third step must be limited in scope to correspond to acts in the specification -- specifically, the sensor's act of giving feedback to the power supply. My construction of "adjustable power supply" makes this additional argument superfluous.

[57] [*808] 4. Claims 11, 12, 15, 16, and 18**

The parties do not dispute the meanings of these method claims, all of which depend from claim 10. Each parallels a dependent apparatus claim. For example, claim 11 takes the substance of claim 2 and gives it the nomenclature of a method claim. Likewise, claim 12 parallels claim 3, claim 15 parallels claim 6, claim 16 parallels claim 7, and claim 18 parallels claim 9.

V. Comparison with Accused Products

I now turn to the second step of the literal infringement analysis: comparing the properly construed claims with the product or process accused of infringement. See *Markman, 52 F.3d at 976*. Many infringement arguments are now moot in light of my claim construction. I address only those that survive.

A. The *'645 Patent*

1. Dialight's Accused Products

Relume has accused two Dialight products of literally infringing claim 1 of its *'645 patent*: Dialight's 8" and 12" LED traffic signals. Dialight argues that its products do not literally infringe claim 1 because, inter alia, they lack a required element -- they do not generate regulated voltage.

Dialight's supporting evidence consists of a declaration [**58] by its expert, Rand Eikelberger, who is Dialight's Vice President for Engineering, and circuitry diagrams attached as exhibits to Eikelberger's declaration. Referring to these diagrams, Eikelberger states in his declaration that Dialight's accused products use "a current regulator circuit," the output of which is "regulated (i.e., constant total) current." (Eikelberger Decl. at P 4.) He explains that the regulator uses current sense resistors to provide feedback about its output so that it can change the ON/OFF ratio of its switching and thereby alter the current flowing to the LED array. (See id. at PP 11-13.) He states that he witnessed tests of Dialight's accused products, in which some strings of the LED array were purposefully shorted, and saw that the current output of the regulator remained essentially constant despite the short circuits in the array. (See id. at PP 7-8 & Ex. 2.) And he also points out that the lack of ballast resistors in Dialight's accused products is further evidence of current regulation because ballast resistors are current controlling devices that are unnecessary, even wasteful, in arrays already supplied current regulated power by a switching [**59] power supply. (See id. at PP 15-18.)

Dialight's evidence satisfies its *Rule 56(c)* burden of showing that no genuine issue of material fact exists because that evidence establishes that Dialight's "converter means" is designed to generate stabilized current. See *Celotex, 477 U.S. at 323*. In other words, Dialight has met its burden of showing that its accused products do not generate regulated voltage within the meaning of claim 1 of the *'645 patent*. This consequently triggers Relume's *Rule 56(e)* burden "to set forth specific facts showing that there is a genuine issue for trial."

Relume lists the following as evidence of Dialight's voltage regulation: 1) an advertisement and a marketing press release that state that Dialight's accused products have voltage regulation; 2) tests performed by Hochstein on Dialight's accused products that indicate they keep voltage essentially constant across the LEDs (when resistance is constant) despite input line voltage fluctuations between 80 and 135 volts a.c., (see Hochstein Reply Decl. [*809] at P 4); and 3) a statement by Relume's expert, Thomas Gafford, that Dialight's current sense resistors are also ballast resistors in that [**60] they have some ballasting effect, (see Gafford Noninfringement Decl. at PP 6-8). Relume asserts that this meager body of evidence creates a genuine issue of material fact as to whether the "converter means" of Dialight's accused products generates regulated voltage within the meaning of claim 1.

I disagree. Under the construction of claim 1 that I have adopted, Relume's evidence does not constitute proof of Dialight's literal infringement of the "generating regulated voltage" limitation because it leaves undisputed Dialight's evidence that shows its accused products have a "converter means" that is designed to regulate current. The material fact at issue here is whether Dialight's "converter means" is designed for generating regulated voltage. Even taken in a light most favorable to Relume, all that Relume's evidence demonstrates is that Dialight's marketing department thought its accused products

regulated voltage, that Dialight's current-regulating "converter means" produces the same effect as a voltage-regulating "converter means" in the limited condition where Ohm's Law predicts it would, and that current sense resistors may have a mild ballasting effect because they indirectly [**61] affect voltage. None of Relume's evidence stands as direct proof that Dialight's "converter means" does not regulate current -- in other words, is not designed for the purpose of generating regulated current at its output.

Indeed, Relume and its expert admit as much. Both effectively acknowledge that Dialight's "converter means" is designed to regulate current. (See Pl.'s Consolidated Opp. at 37 & 54.) Given my construction of "generating regulated voltage," this factual concession prevents a jury from reasonably finding in favor of Relume as a matter of law. Relume has simply failed to satisfy its *Rule 56(e)* burden of submitting "specific facts" sufficient to show a genuine issue for trial. I therefore hold that summary judgment of literal noninfringement in favor of Dialight is appropriate with respect to claim 1 of the *'645 patent*. Because dependent claims 2, 4, 5, and 6 also incorporate the "generating regulated voltage" limitation, I further hold that summary judgment of literal noninfringement in favor of Dialight is appropriate with respect to those claims as well.

2. Ecolux's Accused Product

As Dialight does, Ecolux argues that its accused product does not literally [**62] infringe claim 1 because its "converter means" generates regulated current. Ecolux had two experts testify by declaration that its power supply is designed to regulate current. The first is Mohammed Ghanem, an electrical engineer employed by Ecolux, who states in his declaration that "Ecolux uses a current regulation flyback switch mode converter and therefor [sic] does not use the same approach" as Relume's *'645 patent*. (Ghanem Decl. at 2.) The second is Barry Feinberg, a retained expert, who states in his declaration that "the Ecolux power supply is a regulated current supply or acts as a constant current supply." (Feinberg Decl. at 6.) I find that these expert declarations suffice to satisfy Ecolux's *Rule 56(c)* burden.

Once again, however, Relume does not dispute the fact that Ecolux's "converter means" is designed to regulate current, (see Pl.'s Consolidated Opp. at 36 & 53), but argues instead that its tests show that when resistance is constant and line input voltage varies, the voltage across the LEDs of the accused product remains essentially constant. This is the same literal infringement theory I rejected in my claim construction and in my analysis of Dialight's accused [**63] products. Accordingly, Relume has again failed to satisfy its *Rule 56(e)* burden of showing a genuine issue of material fact under the construction of "generating regulated voltage" I have adopted. What evidence Relume has against Ecolux's current-regulating "converter [*810] means" only pertains to whether it incidentally keeps voltage constant in the limited circumstance where Ohm's Law predicts that it would.

I therefore hold that summary judgment of literal noninfringement in favor of Ecolux is appropriate with respect to claim 1 of the *'645 patent*, as well as with respect to the dependent claims, claims 2, 4, 5, and 6.

3. Precision's Accused Product

Precision also argues that its accused product does not literally infringe claim 1 of the *'645 patent* because its "converter means," or interface circuit, is designed to regulate current. As supporting evidence, Precision submits declarations from two experts, Bradford Perry, an electrical engineer at Precision who designed the interface circuit, and Alex Severinsky, a retained expert, both of which establish in detail that Precision's interface circuit is designed to produce regulated current at its output. (See Perry Decl. at [**64] PP 15-20; Severinsky Decl. at PP 12-25.) Of particular note in these declarations is the observation made by both experts that Precision's interface circuit does not have a controller that performs voltage output monitoring -- in other words, it lacks an output voltage feedback loop. (See Perry Decl. at P 21; Severinsky Decl. at P 18.) Precision's expert declarations more than suffice to satisfy its *Rule 56(c)* burden on summary judgment.

As with Dialight and Ecolux, Relume does not dispute that Precision's "converter means" is designed to regulate current. (See Pl.'s Consolidated Opp. at 33 & 52.) The evidence Relume does offer against Precision is the same flawed body it offered against Ecolux. Thus under the construction I have adopted for the "generating regulated voltage" limitation, Relume has failed to satisfy its *Rule 56(e)* burden. I therefore hold that summary judgment of literal noninfringement in favor of Precision is appropriate with respect to claim 1 of the *'645 patent*, as well as with respect to the dependent claims, claims 2, 4, 5, and 6.

4. Lumileds' Accused Product

Lumileds argues that its accused product does not literally infringe claim 1 because [**65] its "converter means" is designed to regulate current, not voltage. For support, it submits a declaration by its retained expert, Professor Robert Erickson, who concludes that "the power supply used in the Lumileds traffic light performs current regulation, not voltage regulation." (Fourth Erickson Decl. at P 41.) He bases this conclusion in part on his observation that "the [Lumileds] power supply does not monitor the output voltage, but instead monitors the current through the LED array." (Id.) He also observes that because the Lumileds power supply regulates current, there are no ballast resistors in the array of the accused product. (Id. at P 15-22.) Erickson's declaration satisfies Lumileds' *Rule 56(c)* burden.

In response, Relume fails to dispute Erickson's conclusion that Lumileds' "converter means" is designed to regulate current. As with the other three defendants, it acknowledges that Lumileds' "converter means" generates regulated current. (See Pl.'s Consolidated Opp. at 39 & 55.) The evidence it offers against Lumileds is for all purposes nearly identical to the immaterial evidence it offered against Dialight. Thus under the construction I have adopted for [**66] the "generating regulated voltage" limitation, Relume has failed to satisfy its *Rule 56(e)* burden. I therefore hold that summary judgment of literal noninfringement in favor of Lumileds is appropriate with respect to claim 1 of the *'645 patent*, as well as with respect to the dependent claims, claims 2, 4, 5, and 6.

B. The *'909 Patent*

1. Dialight's Accused Product

Dialight utilizes two different temperature compensation devices in its LED traffic signals: the "op amp" device [*811] and the "current shunt" device. Relume has asserted that both literally infringe claims 1, 2, 3, 6, 7, 9-12, 15, 16, and 18 of its *'909 patent*. In its summary judgment motion, Dialight argues only that its "current shunt" device does not literally infringe Relume's asserted claims.

There is no factual dispute regarding the structure and operation of Dialight's "current shunt" device. As explained by Dialight's expert, Mr. Eikelberger, it consists of a voltage-regulating switching power supply, a variable load with a thermistor circuit, and a series-parallel LED array. (See Eikelberger Decl. at PP 5-9.) The switching power supply supplies fixed or constant d.c. pulses to the variable load and [**67] the LED array. (See id.) If the temperature sensed by the thermistor increases, the thermistor sends a signal to the variable load to increase its impedance of the current supplied by the power supply. (See id. at PP 9-10.) As the impedance of the variable load increases, it diverts, or "shunts," more current to the LED array. (See id.) The increase in current shunted to the LED array compensates for the decrease in LED illumination due to increased temperature and thus maintains the LED array's luminous intensity. (See id.)

Dialight argues that this "current shunt" device does not literally infringe claim 1 of the *'909 patent*, as well as its dependent claims 2, 3, 6, 7, and 9, because the device's switching power supply is not responsive to the luminous output signal of a sensor as required by claim 1. Dialight explains that the sensor, or thermistor, used in its device sends its luminous output signal to the variable load, not the device's switching power supply. Relume does not dispute this fact. Therefore, because Dialight's "current shunt" device lacks a power supply responsive to a luminous output signal from a sensor, I hold that a summary judgment of literal [**68] noninfringement in favor of Dialight is appropriate with respect to claims 1, 2, 3, 6, 7, and 9 of the *'909 patent*.

Dialight also argues that its "current shunt" process does not literally infringe method claim 10, as well as its dependent claims 11, 12, 15, 16, and 18, because the accused process does not use an "adjustable power supply" as required by the "supplying" step of claim 10. Under the construction that I have adopted for the "adjustable power supply" limitation, Relume must establish that Dialight's accused process uses a switching power supply that is responsive to a luminous output signal from a sensor so that the ON/OFF current pulses supplied by the power supply can be adjusted in their frequency or pulse width. Relume cannot establish this, however, because it is not in dispute that Dialight's accused process uses a switching power supply that is not responsive to a luminous output signal from a sensor.

Therefore, because Dialight's "current shunt" process lacks the "adjustable power supply" limitation, I hold that summary judgment of literal noninfringement in favor of Dialight is appropriate with respect to claims 10, 11, 12,

15, 16, and 18.

2. Ecolux's Accused [69] Product**

Ecolux argues that its temperature compensation device for LED traffic signals does not literally infringe claims 1-3, 6, 7, and 9 of the *'909 patent* because it lacks a sensor that senses a "condition proportional" to the luminous output of the LEDs. Ecolux's expert, Barry Feinberg, states in his declaration that because Ecolux's temperature sensor is mounted on the power supply circuit board, and not in with the LEDs, it is not in "a location to measure temperature of the LEDs in the device." (Feinberg Decl. at P 9.) He also states that "the Ecolux thermistor temperature sensor senses the temperature changes in the enclosure due to all energy sources, i.e. electrical and thermal in the form of conduction and radiation." (Id.)

As the construction I adopted for "condition proportional" made clear, the [*812] location of the sensor is irrelevant to that claim limitation. Thus as long as a sensor senses a condition that has some fixed relation with the LEDs' light output, it qualifies as the "sensor" recited in claim 1. Ecolux's evidence does not establish that its temperature sensor does not perform the sensing function of claim 1. It is possible that the ambient temperature [**70] sensed by Ecolux's sensor bears some fixed relation to the LEDs' light output. Ecolux has therefore failed to satisfy its *Rule 56(c)* burden. I hold that summary judgment of literal noninfringement in favor of Ecolux is not appropriate because Ecolux has not shown that a genuine issue of material fact does not exist as to whether its sensor senses a "condition proportional."

3. Lumileds' Accused Product

Lumileds argues that its accused product does not literally infringe any of the asserted claims of the *'909 patent* because it does not maintain the luminous output of its LEDs at a predetermined level. As evidence, Lumileds offers a graph that shows the luminous output of its LEDs declining by 50% as the ambient temperature increases from - 40 degrees Celsius to 74 degrees Celsius (the industry's specified operating range for traffic lights). (See Fourth Erickson Decl. at P 48 & Ex. 23.)

Relume does not dispute the fact of the 50% decline. Rather, it argues that that decline must be considered essentially constant light output in light of the prior art loss of nearly 100% over the same operating range. (See Pl.'s Consolidated Opp. at 49.) This is of course the wrong [**71] comparison to be made. To establish literal infringement, Relume must compare the properly construed claims of the *'909 patent* to Lumileds' accused product, not Lumileds' accused product to the prior art. See *Becton, 922 F.2d at 796.* The construction I adopted for the "maintain...at a predetermined level" limitation requires Relume to show that Lumileds' accused product keeps, or preserves from decline, the luminous output of its LEDs at an amount chosen beforehand. No jury could reasonably find that Lumileds' undisputed 50% decline in luminous output complies with the plain meaning of this claim limitation. See *Liberty Lobby, 477 U.S. at 252.*

I therefore hold that summary judgment of literal noninfringement in favor of Lumileds is appropriate with respect to claims 1-3, 6, 7, 9-12, 15, 16, and 18 of the *'909 patent* because its accused product lacks the "maintain...at a predetermined level" limitation that all those claims require.

VI. Validity

Lumileds has raised two validity challenges to Relume's *'645* and *'909 patents*. With the first, Lumileds contends that certain claims of both patents are invalid because they were anticipated by [**72] prior art. With the second, Lumileds contends that all asserted claims of both patents are invalid because they would have been obvious to one of ordinary skill in the art at the time they were invented.

Federal statute requires that "each claim of a patent (whether in independent, dependent, or multiple dependent form) shall be presumed valid independently of the validity of other claims." *35 U.S.C. § 282.* "The presumption of validity under *35 U.S.C. § 282* carries with it a presumption that the examiner did his duty and knew what claims he was allowing." *Intervet America, Inc. v. Kee-Vet Lab., Inc., 887 F.2d 1050, 1054 (Fed. Cir. 1989).* In raising its validity challenges, Lumileds has the burden of showing invalidity of each claim by clear and convincing evidence. See *North American Vaccine, 7 F.3d at 1579.*

A. Anticipation

"Under *35 U.S.C. § 102*, every limitation of a claim must identically appear in a single prior art reference for it to anticipate the claim." *Gechter v. Davidson, 116 F.3d 1454, 1457 (Fed. Cir. 1997).* [*813] "There must be no

difference between [**73] the claimed invention and the reference disclosure, as viewed by a person of ordinary skill in the field of the invention." *Scripps Clinic & Research Found. v. Genentech, Inc., 927 F.2d 1565, 1576 (Fed. Cir. 1991).* Anticipation is a question of fact. See *Glaxo Inc. v. Novopharm Ltd., 52 F.3d 1043, 1047 (Fed. Cir. 1995).* Thus "for summary determination to be proper, there must be no genuine dispute whether the limitations of the claimed invention are disclosed, either explicitly or inherently, by an allegedly anticipating prior art reference." *Hazani v. U.S. Int'l Trade Comm'n, 126 F.3d 1473, 1477 (Fed. Cir. 1997).*

In its response motion on the issue of obviousness, Relume alleges that I have already denied Lumileds' earlier motion for summary judgment on the issue of anticipation. This is incorrect. I reserved my ruling on Lumileds' pending anticipation motion so that, inter alia, I could efficiently decide all dispositive issues raised by the parties in one ruling.

1. The *'645 Patent*

Lumileds asserts that *U.S. Patent No. 5,463,280* issued October 31, 1995 to James C. Johnson ("the Johnson patent" or "Johnson") anticipates [**74] claims 1, 2, and 4 of the *'645 patent.* Relume does not dispute that the Johnson patent is prior art to the *'645 patent* as defined by *35 U.S.C. § 102(a)* or *(e).* [21] Relume did not present the prior art Johnson patent to the patent examiner when it filed its application for the *'645 patent.*

21 *Section 102(a)* states: "A person shall be entitled to a patent unless -- (a) the invention was known or used by others in this country, or patented or described in a printed publication in this or a foreign country, before the invention thereof by the applicant for patent."

Section 102(e) states in pertinent part: "A person shall be entitled to a patent unless...(e) the invention was described in a patent granted on an application for patent by another filed in the United States before the invention thereof by the applicant for patent."

Johnson teaches using LEDs to replace incandescent bulbs in illuminated signs such as exit signs. (See Johnson, 1:6-10.) Johnson discloses a variety of circuitry [**75] configurations for LED arrays and their power supplies. One such configuration -- the embodiment depicted in Figure 8 of Johnson -- teaches a simple series LED array [22] that is supplied electrical power by a rectifier and a switching power supply. Of all the configurations in the Johnson patent, this one comes closest to possessing all the limitations of claim 1 of the *'645 patent.* I find, however, that it explicitly lacks one limitation found in claim 1. Specifically, while Johnson expressly teaches a switching power supply that performs power factor correction, it does not expressly state that the power supply also performs a "generating regulated voltage d.c. power" function -- a function required by claim 1 of the *'645 patent.* (See Johnson, 6:67 to 7:10.) Thus the Johnson patent's switching power supply is not explicitly identical to the switching power supply of claim 1.

22 Relume's primary argument against the anticipation of claim 1 by the Johnson patent relied on its erroneous, series-parallel construction of "LED array." Under the construction I have adopted for that phrase, the series LED array disclosed in the Johnson patent falls within the scope of the *'645 patent*'s "LED array" element.

[**76] The question then becomes whether Johnson inherently discloses a voltage-regulating switching power supply that is identical to that of claim 1. To show an inherently anticipating disclosure on summary judgment, Lumileds must clearly and convincingly establish that there is no genuine issue as to whether claim 1's voltage-regulating switching power supply is "necessarily present" in the Johnson patent and "that it would be so recognized by persons of ordinary skill." *Electro, 34 F.3d at 1052.* The undisputed evidence does establish this. Specifically, Professor Erickson has concluded that a person of [*814] ordinary skill in the art would have recognized that the MC 34261 Motorola power factor controller recommended by the Johnson patent for use in its switching power supply was "designed to be used in a voltage regulated power factor correction converter." (Third Erickson Decl. at P 17.) This is so, Erickson states, because the Motorola controller "is designed with a 'voltage feedback input'...which typically is used to monitor the output voltage for voltage regulation." (Id.) Relume does not contest Erickson's conclusion.

Accordingly, I hold that summary judgment of [**77] invalidity is appropriate because Lumileds has clearly and convincingly shown that no genuine issue of material fact exists as to the anticipation of claim 1 by the

Johnson patent's identical device.

Lumileds also argues that the Johnson patent anticipates the invention of claim 2 of the *'645 patent*. Claim 2 specifies that the power factor correction converter means is "a power factor correcting and voltage regulating buck/boost switchmode converter." '645, 13:33-36. Because the Johnson patent explicitly discloses a switchmode converter (or switching power supply), Lumileds argues that Johnson inherently discloses a buck/boost switchmode converter. I do not find, however, that the Johnson patent supports this conclusion as a matter of law. The evidence in this case establishes that a person of ordinary skill in the art would recognize that a switchmode converter has three forms: buck, boost, and buck/boost. Johnson does not disclose that any one of those forms must necessarily be associated with its switchmode converter. Thus the fact that three possible forms exist precludes the argument that any one form is necessarily present. See *Continental Can Co. USA, Inc. v. Monsanto Co., 948 F.2d 1264, 1268-69 (Fed. Cir. 1991)* **[**78]** (concluding that feature that "may result" from prior art configuration is not an "inherent" feature").

Accordingly, I hold that summary judgment on the issue of anticipation is inappropriate with respect to claim 2 of the *'645 patent* because Lumileds has failed to present sufficient evidence showing that a buck/boost switchmode converter would be necessarily present in the Johnson device.

Finally, Lumileds contends that the Johnson patent also anticipates claim 4 of the *'645 patent*. Claim 4 requires the additional element of an "electromagnetic interference filter means." '645, 13:43. The Johnson patent lacks an electromagnetic interference filter ("EMI filter"). Lumileds argues that it inherently discloses one because federal regulations now require EMI filters and the data sheet for the MC 34261 Motorola controller discloses using an EMI filter in combination with the controller. At best, Lumileds' evidence raises a genuine issue of material fact as to whether Johnson inherently discloses an EMI filter. The Motorola data sheet only proves that an EMI filter can be used with the Johnson device, not that it necessarily results from Johnson. As for the federal regulation, it is not **[**79]** clear from the section referred to by Professor Erickson, 47 C.F.R. Part 15, whether it even applies to the Johnson device, whether it was in effect at the time of the Johnson device's invention, or whether it would require an EMI for compliance.

Accordingly, I hold that summary judgment on the issue of anticipation is inappropriate as to claim 4 of the *'645 patent* because Lumileds has not offered evidence sufficient to satisfy its *Rule 56(c)* burden.

2. The *'909 Patent*

Lumileds asserts that a Japanese patent filed by Fujitsu Co., Ltd. in January 1987 and published in July 1988 as publication No. 63-178221 ("the Fujitsu publication" or "Fujitsu") anticipates claims 1-3, 7, 10-12, and 16 of the *'909 patent*. Relume does not dispute that the Fujitsu publication is prior art to the *'909 patent* as **[*815]** defined by *35 U.S.C. § 102(b)*. [23] Relume did not present the prior art Fujitsu publication to the patent examiner when it filed its application for the *'909 patent*.

> 23 *Section 102(b)* states: "A person shall be entitled to a patent unless...(b)the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of the application for patent in the United States."

[80]** The translated Fujitsu publication is entitled "Lighting Circuit for LED Array for Illumination." (Lumileds' Anticipation Mot. at Ex. 7.) It states that the object of its invention is "to provide a lighting circuit which is not affected by temperature changes and whose illumination output light is always of constant intensity and good efficiency." (Id.) The Fujitsu publication's sole claim reads as follows:

A lighting circuit for an LED array for illumination, comprising:

> LED array (1),
>
> temperature detection means (2) provided at this LED array (1),
>
> lighting control circuit (3) which inputs a temperature signal from this temperature detection means (2) and outputs a pulse signal whose duty ratio is controlled in accordance with the relevant temperature signal, and

> power source (4) connected to said LED array (1) via this lighting control circuit (3)

(Id.) Fujitsu's "lighting control circuit" regulates the electrical pulses or "signal pulses" it sends to the LED array by the use of a switch or "switching transistor T." (Id.) Fujitsu explains that the "switching transistor T has the role of turning on and off the electricity from the power source 4, which [**81] is supplied to LED array 1." (Id.) These facts about the components and operation of the Fujitsu invention are undisputed. Indeed, Relume does not, and cannot, contest that Fujitsu discloses a device that has exactly the same purpose as the device of its *'909 patent*: to maintain the luminous output of LEDs at a predetermined level through the use of a sensor feedback loop and an adjustable power supply.

Relume's entire argument against the anticipation of claim 1 by Fujitsu is this: the Fujitsu device lacks a power supply that includes a switch. [24] In other words, Relume believes that the Fujitsu switch is not within the Fujitsu power supply as required by the "including" limitation of claim 1. Relume's reasoning in support of its argument: the Fujitsu "power source" is really its power supply and thus Fujitsu's switch, which is located in the lighting control circuit and not in the power source, lies outside its power supply.

> 24 This is also Relume's only argument against the anticipation of claims 2, 3, 7, 10, 11, 12, and 16 by Fujitsu.

[**82] My analysis of Relume's argument begins with the construction I adopted for the "including" limitation of claim 1. I determined that the intrinsic evidence of the *'909 patent* would lead a person of ordinary skill in the art to understand "said power supply (16) including a switching device" to mean that a switching power supply was required. As has been well established, a switching power supply must have at least two basic components: a converter, or switch, and its controller circuit. It is also well established by the totality of evidence in this case that a switching power supply's function is to take incoming electrical power from some existing power source and convert it (thus the label "converter") into whatever form of electrical power -- voltage-regulated, current-regulated, power factor corrected, etc. -- works best for the device to which it supplies power. Thus a switching power supply does not make power; rather, it transforms (modifies, regulates) already generated power according to the needs of the load it serves (in this case, an LED array).

[*816] These fundamental realities of the art make it clear that Fujitsu's lighting control circuit, not its power source, is a switching [**83] power supply in design and function. It has a switch -- the "switching transistor T" -- and it has circuitry that controls the turning on and off of that switch. It is also "responsive to said luminous output signal for adjusting the electrical energy supplied by said pulses per unit of time to adjust the average of said current passing through said LED." '909, 7:8-11. As Fujitsu explains:

> Temperature detection means 2 detects the temperature of LED array 1 and sends a temperature signal to lighting control circuit 3. Based on this temperature signal, lighting control circuit 3 controls the duty ratio of a constant cycle lighting pulse to the desired value, and the electricity from power source 4 is turned on and off, and LED array 1 is lighted, and the amount of light is controlled to be constant.

(Lumileds' Anticipation Mot. at Ex. 7.) Thus Fujitsu's lighting control circuit functions as a switching power supply for the particular purpose of LED temperature compensation. It takes incoming power generated elsewhere and converts it into a form of electrical power -- here, pulses of power that vary in their width depending on the temperature sensor's input -- that better [**84] suits temperature-sensitive LEDs and therefore results in a constant level of illumination.

The only evidence Relume has that suggests the lighting control circuit of Fujitsu might not be a switching power supply is the conclusory statement of its expert, Thomas Gafford, (see Gafford Decl. at PP 17-19), and the fact that the *'909 patent* just once appears to use the phrases "power source" and "power supply" synonymously, see '909, 5:1-3. I reject Gafford's opinion on this point because his conclusory assessment is without a reliable factual foundation [25] and because it ignores the voluminous evidence on record -- the *'645 patent*, the *'909 patent*, the Power Supply Cookbook, etc. -- that attests to the basic structure and identity of switching power supplies. See *Union Carbide Corp. v. American Can Co., 724 F.2d 1567, 1572 (Fed. Cir. 1984)*

. As to the *'909 patent*'s statement in question -- "switch mode supplies include any power source 16 that is turned on and off" -- I find that it actually works against Relume because the Fujitsu publication explicitly describes the lighting control circuit performing the exact same function.

25 In attempting to rebut Lumileds' evidence, Gafford does not conduct an analysis of the structure and function of Fujitsu's lighting control circuit and then explain how the circuit differs from the structure and function of switching power supplies as understood in the art. Gafford simply assumes from the outset that Fujitsu's "power source" is Fujitsu's power supply. The Supreme Court's recent decision in *Kumho Tire Co. v. Carmichael, 526 U.S. 137, 119 S. Ct. 1167, 143 L. Ed. 2d 238 (1999)*, requires me to perform a gatekeeping role as to all proffered expert testimony. See *119 S. Ct. at 1174*. Because I find Gafford's opinion on the issue of the lighting control circuit's identity to be unreliable, I reject it pursuant to Kumho.

Furthermore, it is revealing to contrast Gafford's opinion on this issue with the opinion of Lumileds' expert, Professor Erickson, who conducts a precise and cogent examination of the Fujitsu lighting control circuit and explains how one of ordinary skill in the art would recognize it as a switching power supply. (See Third Erickson Decl. at PP 40-49.) I find that this section of Professor Erickson's declaration constitutes additional clear and convincing evidence that the Fujitsu lighting control circuit is a switching power supply.

[**85] Accordingly, I find that there is no genuine issue of material fact as to whether Fujitsu's lighting control circuit is a switching power supply as understood by those of ordinary skill in the art. The question then becomes whether Fujitsu's lighting control circuit is explicitly identical in every limitation to the "switching device" element recited by claim 1 of the *'909 patent*. See *Gechter, 116 F.3d at 1457*. I find that it is. It is undisputed fact that Fujitsu's lighting control circuit has a switch or switching device, that its [*817] switching device is responsive to the feedback of a sensor that senses a condition proportional to the LEDs' luminous output, and that the switching device responds to the sensor's signal by adjusting the current pulses it supplies to the LEDs (and thus the average current in the LEDs) in order to maintain the LEDs' luminous output at a predetermined level. See '909, 7:7-12.

It is also undisputed fact that the Fujitsu reference explicitly discloses the three other elements of claim 1. It teaches "at least one light emitting diode," its thermistor is explicitly "a sensor...for sensing a condition proportional to said luminous output [**86] of said LED (12) and for producing a luminous output signal," and its lighting control circuit would be recognized by one of ordinary skill in the art as "a power supply (16) electrically connected to said LED (12) for supplying ON/OFF pulses of electrical energy to produce the luminous output of said LED." See '909, 6:66 to 7:6. Because there is "no genuine dispute" that the prior art Fujitsu publication explicitly discloses every limitation of claim 1 of the *'909 patent*, and thus anticipates claim 1, I hold that summary judgment of invalidity is appropriate with respect to claim 1. *Genentech, 927 F.2d at 1576*. I also hold that summary judgment of invalidity is appropriate with respect to claim 10 because the recited method of claim 10 parallels claim 1 in its elements. [26]

26 My claim construction of claim 10's "adjustable power supply," which determined that the phrase required a switching power supply responsive to the sensor's luminous output signal, resolves Relume's argument that Fujitsu does not disclose an "adjustable power supply." This was Relume's only argument against the anticipation of claim 10 by Fujitsu.

[**87] Dependent claim 2 and the parallel method of dependent claim 11 recite a means, or a step, for "sensing changes in the temperature of said LED (12)." It is an undisputed fact that Fujitsu explicitly discloses a thermistor that senses the temperature of the LEDs. Accordingly, summary judgment of invalidity is appropriate with respect to the anticipation of claims 2 and 11 by Fujitsu.

Dependent claim 3 and the parallel method of dependent claim 12 require the sensing means or step to include "a predetermined temperature behavior model." It is an undisputed fact that the Fujitsu publication explicitly discloses an electronic chip pre-programmed with an LED temperature behavior model that is used in conjunction with the sensor's luminous output signal. The specification of the *'909 patent* discloses the same type of

chip with the same function. Accordingly, summary judgment of invalidity is appropriate with respect to the anticipation of claims 3 and 12 by Fujitsu.

Dependent claim 7 and the parallel method of dependent claim 16 require the switching device, or "adjusting" step, to adjust the electrical pulses by adjusting their width. It is an undisputed fact that Fujitsu explicitly [**88] discloses a switching device that adjusts its electrical pulses by adjusting their width. Accordingly, summary judgment of invalidity is appropriate with respect to the anticipation of claims 7 and 16 by Fujitsu.

B. Obviousness

According to *35 U.S.C. § 103*, prior art invalidates a patent for obviousness when the "subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which the subject matter pertains." See, e.g., *Richardson-Vicks, Inc. v. Upjohn Co., 122 F.3d 1476 (Fed. Cir. 1997)* (holding patent invalid for obviousness). An obviousness inquiry under *section 103* ultimately presents a question of law. See *In re Donaldson Co., Inc., 16 F.3d 1189, 1192 (Fed. Cir. 1994)* (unanimous *en banc* decision). In answering that question, I must address four underlying factual considerations: [*818] (1) what is the scope and content of the prior art; (2) what are the differences, if any, between the claims at issue and the prior art; (3) what would have been the level of ordinary skill in [**89] the prior art at the time of the invention; and (4) are there any secondary considerations of non-obviousness. See *Graham v. John Deere Co., 383 U.S. 1, 17, 15 L. Ed. 2d 545, 86 S. Ct. 684 (1966)*.

Lumileds argues that resolution of these four factual inquiries clearly and convincingly establishes that the remaining asserted claims of the *'645 patent* -- claims 2, 4, 5, and 6 -- and the *'909 patent* -- claims 6, 9, 15, and 18 -- are invalid for obviousness in light of the relevant prior art at the time of their invention. Relume argues that genuine issues of material fact exist that preclude summary judgment on the issue of obviousness.

1. The Scope and Content of the Prior Art

The Federal Circuit has repeatedly held that the scope of the relevant prior art consists of those references "reasonably pertinent to the particular problem with which the inventor was involved." *In re GPAC, Inc., 57 F.3d 1573, 1577 (Fed. Cir. 1995)*. "Therefore, the prior art relevant to an obviousness determination necessarily encompasses not only the field of the inventor's endeavor but also any analogous arts." *Id. at 1577-78*. Accordingly, in determining [**90] whether a reference is from a relevant prior art, I "first must determine whether the reference is within the inventor's field of endeavor, and if it is not [I] next must determine whether the reference is reasonably pertinent to the particular problem confronting the inventor." *Id. at 1578*.

Relume believes there is a genuine dispute concerning the fields of endeavor for both of its patents. It contends that the field of the inventor's endeavor for the *'645 patent* is "clearly no broader than LED array traffic signals." (Pl.'s Obviousness Opp. Mot. at 7.) Relume also contends that the field of endeavor for the *'909 patent* is "safety-critical outdoor LED signals." (*Id. at 8*.) Relume's contentions rely on Gafford's reading of the patents. (See Gafford's Obviousness Decl. at PP 8-11).

Lumileds contends that the field of endeavor for the *'645 patent* is "power supplies, power supplies for LEDs, and circuits for preventing leakage current." (Lumileds' Obviousness Mot. at 16.) Lumileds also contends that the field of endeavor for the *'909 patent* is "techniques for maintaining the luminous output of an LED when temperatures rise." (Lumileds' Reply Br. at 15.) Lumileds' [**91] contentions rely on Professor Erickson's reading of the patents, (see Third Erickson Decl. at PP 8 & 41), and the deposition testimony of Hochstein, the patents' inventor.

I find no genuine dispute in the evidence regarding the *'645 patent*'s field of endeavor. Lumileds' understanding of the '645's field fully reflects both the patent's own statement of its field and the inventor's own understanding of his field of endeavor. The *'645 patent* states at its outset that its invention "relates generally to an apparatus for generating power to a light emitting diode array and, in particular, to a power supply for operating light emitting diode array traffic signals." '645, 1:5-8. Gafford's opinion focuses exclusively on the second half of this statement -- everything after the "in particular" -- and so he ignores the full scope of the patent's own definition of its field. Gafford's opinion also ignores the specification's unrestricted description of its invention as "an apparatus for supplying regulated

voltage d.c. electrical power to an LED array." '645, 3:18-19. Finally, Gafford's opinion clashes with Hochstein's own identification of his field of endeavor as being a.c. powered LED [**92] arrays. 27 (See Hochstein Dep. at 163-64.)

> 27 Here is the pertinent section of Hochstein's deposition:
>
> > Q Now, your patent, the *645 patent*, you're saying is only limited to AC LED arrays?
> >
> > A No. It's limited to what the claims say it's limited to. It's an LED array driven from the AC power line with power factor controller and voltage regulation.
> >
> > Q It doesn't have to be a traffic light; correct?
> >
> > A No. It has to be an AC-powered device.
> >
> > Q Any AC-powered device?
> >
> > A An AC-powered array of LEDs. That has voltage regulation power factor control and the dependent claims.
>
> (Hochstein Dep. at 163-64.) Reinforcing this testimony and Lumileds' understanding of the patent's field of endeavor, the specification mentions that a.c. powered LED arrays have many "common applications" beyond traffic lights -- for instance, as "status annunciators, message boards, liquid crystal display back lights." '645, 1:11-17.

[*819] For all of these reasons, then, I find that Gafford's opinion on this [**93] issue is "not significantly probative" and thus fails to create a genuine issue of material fact as to the field of the inventor's endeavor for the *'645 patent*. See *Liberty Lobby, 477 U.S. at 249-50*. Accordingly, I adopt the field proposed by Lumileds. I specifically find that the inventions of claims 2 and 4 are within the field of power supplies for a.c. powered LED arrays and that the inventions of claims 5 and 6 are within the field of power supplies for a.c. powered LED arrays that use circuits to prevent leakage current.

I likewise find no genuine dispute in the evidence regarding the *'909 patent*'s field. Lumileds' understanding of its field again enjoys the full support of the patent and its inventor. To begin with, the *'909 patent* states that the technical field of its "subject invention relates to light emitting diodes" and nothing else. '909, 1:4-5. It describes its invention as a "circuit for maintaining the luminous intensity of a light emitting diode." '909, 2:7-8. The preferred embodiments mention no restriction to safety critical outdoor signals and neither do the claims. Furthermore, while the specification's background section evinces a concern for [**94] LED temperature degradation in safety-critical outdoor applications, it does not state that the invention only has significance for those applications. This makes sense given that all LEDs, regardless of whether they are used indoors or outdoors, can suffer from degradation of their luminous output due to temporarily increased operating temperatures or the passage of time. Finally, Hochstein himself was adamant that the invention of the *'909 patent*, and thus his field of endeavor, involved circuits for maintaining LED luminous intensity. 28 (See Hochstein Dep. at 163.)

> 28 Here is the pertinent section of Hochstein's deposition:
>
> > Q What two applications?
> >
> > A What shows up in the *909 patent*, has nothing to do with AC power supplies.
> >
> > Q Okay. What does it have to do with?
> >
> > A Maintaining luminous intensity of LEDs, period.
> >
> > Q Any type of LEDs?
> >
> > A That's correct. This patent has to do only with AC-powered LED arrays.
> >
> > Q "This" being the *645 patent*?
> >
> > A The *645 patent*.

(Hochstein Dep. at 163.)

[**95] Because Gafford's opinion as to the '909's field ignores these undisputed facts, I find once again that his declaration fails to demonstrate a need for trial. See *Liberty Lobby, 477 U.S. at 249-50.* Accordingly, I adopt the field proposed by Lumileds. I find that the inventions of claims 6, 9, 15, and 18 are within the field of circuits for maintaining the luminous intensity of an LED when temperature rises.

Having determined the field of the inventor's endeavors with respect to both patents, the question then becomes whether the prior art offered by Lumileds falls within those fields. As relevant prior art to the *'645 patent,* Lumileds has submitted the Power Supply Cookbook, the already discussed Johnson patent, the MC 34261 Motorola power factor controller that Johnson recommends in its specification, and *U.S. Patent No. 5,075,601* issued December 24, 1991 to Cleve R. Hildebrand ("the Hildebrand patent" or "Hildebrand"), [*820] which teaches the use of a dynamic load circuit to prevent leakage current from triggering conflict monitors in traffic or pedestrian signals.

The Johnson patent clearly lies within the *'645 patent*'s field; it states that some of its LED array [**96] embodiments can be used with a.c. power. Johnson, 2:42-43. Because Johnson is relevant prior art, so too is the MC 34261 Motorola controller it references. Likewise, the Power Supply Cookbook must also be within the *'645 patent*'s field because it is referred to by the *'645 patent*. '645, 3:13-15. Finally, even though Relume disputes the exact operation and structure of the Hildebrand circuit as compared to its adaptive clamp circuit, it cannot dispute that the Hildebrand circuit functions for the purpose of eliminating leakage current problems. Hildebrand, 1:5-10. Thus Hildebrand is within the field of the inventions of claims 5 and 6. [29]

29 I note that even if Relume's proposed field of endeavor were to be accepted for the *'645 patent*, the prior art offered by Lumileds would still be analogous art because each seeks to address the same problems that Hochstein addressed in the *'909 patent*. See *In re GPAC, 57 F.3d at 1578.* For instance, claim 1 addresses the problems of poor power factor and varying LED illumination due to fluctuating input line voltage. So too do the Johnson patent, the Motorola controller, and the Power Supply Cookbook.

[**97] As relevant prior art to the *'909 patent*, Lumileds has offered the Fujitsu publication and two power supply textbooks -- the Power Supply Cookbook and Bernard Grob's Electronic Circuits and Applications (1982) -- both of which describe (1) various techniques for adjusting on/off pulses of energy from a switching power supply and (2) using filters to convert on/off pulses to substantially direct current ("d.c."). Fujitsu is clearly within the field of the *'909 patent*; as my analysis of the anticipation issue makes clear, both circuits function for the purpose of maintaining the luminous intensity of an LED when temperature rises. Because the use of a switching power supply is necessary to accomplish that function, both power supply textbooks are also within the field of the *'909 patent*. [30]

30 I note again that even if Relume's proposed field of endeavor were accepted for the *'909 patent*, the prior art submitted by Lumileds would still be analogous art because each seeks to address the same problems that Hochstein sought to address in the *'909 patent*. See *In re GPAC, 57 F.3d at 1578.*

[98] 2. The Level of Ordinary Skill in the Art**

I may consider a variety of factors in determining the level of ordinary skill in the art at the time of the alleged invention. See *In re GPAC, 57 F.3d at 1579.* Some of those factors include the "type of problems encountered in the art; prior art solutions to those problems; rapidity with which innovations are made; sophistication of the technology; and educational level of active workers in the field." Id. The time of invention for each asserted claim of the *'645 patent* and the *'909 patent* ranges between December 25, 1994 and January 31, 1996. [31] (See Hochstein Dep. at 83-84 & Dep. Ex. 9.)

31 According to Relume's evidence, Hochstein places his date of conception of each asserted claim of the *'645 patent* accordingly: claim 1 on December 25, 1994; claim 2 on January 31, 1996; claim 4 on April 18, 1995; and claim 5 and 6 also on January 31, 1996. (See Hochstein Dep. at 83-84 & Dep. Ex. 9.) Likewise, for the asserted claims of the *'909 patent*, he has placed conception at the following dates: claims 1, 9, 10, 18 on April 22, 1995; and claims 2, 3, 6, 7, 11, 12, 15, and 16 on January 31, 1996. (See id.) Lumileds has not disputed these dates.

[**99] Lumileds' expert, Professor Erickson, states in his declaration that he "would consider the level of ordinary skill in the art as of the mid 1990's to be at least that of a senior technician with a two year associates degree in electronics and over five years of experience in power electronics or a junior engineer with an undergraduate degree in electrical engineering and at least three years of experience in power electronics." (Third Erickson Decl. at [*821] P 7.) He bases his conclusion on "interactions with people in the industry, consulting with companies, and attending industry conferences." (Id.)

Relume's expert, Mr. Gafford, believes the level of ordinary skill was lower at that time: "at most that of a bachelor's degree in electrical engineering and two to four years experience in that field [LED array traffic signals and safety critical outdoor LED signals]." (Gafford Decl. at P 13.) Gafford bases his opinion on three pieces of evidence: 1) a Dialight patent from mid-1996 that he concludes shows only rudimentary circuitry for its LED product, 2) the fact that Bradford Perry, who is a design engineer for Precision, had no experience in LED signals when he was hired by Precision, [**100] and 3) the fact that Lumileds' 30(b)(6) technical witness, Marcel Bucks, testified that the state of LED traffic light products at the beginning of 1996 was basic. (See *id. at PP 14-17.*)

Relume contends that the disagreement between the experts is a genuine dispute worthy of trial. I disagree. Gafford's analysis is premised on Relume's erroneously restricted view of the relevant fields of endeavor for the two patents. (See *id. at PP 12-13.*) Moreover, his sweeping opinion relies on anecdotal evidence. The Dialight patent, Perry's level of skill, and Buck's testimony [32] do not overcome the evident technological sophistication of the body of relevant prior art on record: that is, the Power Supply Cookbook, [33] the Johnson patent, the Hildebrand patent, the Fujitsu publication, and the prior art cited in the *'645* and *'909 patents*. See *In re GPAC, 57 F.3d at 1579* (noting that review of prior art references provides "valuable insight" into level of skill in the art).

32 Bucks did not testify that the level of ordinary skill in the art was basic in 1996 but only that those products he tested at that time were basic in design because there were no industry specifications requiring anything more. (See Bucks Dep. at 52-54.) He also testified that Philips and Hewlett-Packard were already working on an advanced LED power supply at that time. (See Bucks Dep. at 54-55, 303-05.)

[**101]

33 Notably, the Power Supply Cookbook, which was published in 1994, states in its introduction that switching power supplies are "complicated to design" and "unfamiliar to the typical design engineer." *Id. at 25.*

Indeed, I find the range of relevant prior art to be dispositive as to the question of ordinary skill. It shows that in the fields of both patents, a person of ordinary skill would need to understand not only the design issues associated with LEDs -- their sensitivity to temperature and/or input voltage fluctuations, their degradation over time, etc. -- but also the design issues associated with switching power supplies -- electromagnetic interference, the pros and cons of voltage v. current regulation, power factor correction, etc. Lumileds' proposed level of skill is consistent with the breadth of knowledge required by the inventions of the '645 and the *'909 patents*.

Even if the lesser level of skill offered by Relume were found to have sufficient support in the evidence to create a factual dispute, Relume has not shown that this dispute would have a material bearing on the [**102] non-obviousness inquiry before me. There has been no evidence entered that suggests that Relume's lesser level of skill would preclude a person of ordinary skill in the art from recognizing that the relevant prior art submitted by Lumileds made the asserted claims obvious at the time of their invention.

Accordingly, I find that no genuine issue of material fact exists as to the ordinary level of skill at the time of the invention of the *'645* and *'909 patents*. The evidence clearly and convincingly supports the level of skill proposed by Lumileds. Relume has offered only a "scintilla of evidence" for its position. *Liberty Lobby, 477 U.S. at 252.*

3. Differences, If Any, Between the Invention and the Prior Art

a. Claims 2 and 4 of the *'645 Patent*

Lumileds contends that there is no meaningful difference for obviousness purposes [*822] between the Johnson patent and claim 2 of the *'645 patent*. As stated

before, claim 2 requires that the *'645 patent*'s power factor correction converter means be a buck/boost switchmode converter. The Johnson patent explicitly discloses a switchmode converter but does not specify its type, i.e. whether it is a buck., boost, or buck/boost **[**103]** converter. Professor Erickson has testified that it would have been obvious to one of ordinary skill to use a buck/boost converter with the Johnson device because the Power Supply Cookbook explained how to implement such a circuit for switching power supplies. (See Third Erickson Decl. at P 20.) He explains that "even a skilled technician would know to select a buck/boost converter if the input voltage could be either higher or lower than the desired output voltage." (*Id. at P 19.*)

Relume has only two arguments in response. First, the Johnson patent does not disclose a device with the LED array required by claim 1 because its Figure 8 embodiment lacks a series-parallel configuration. My claim construction of "LED array" has eliminated this argument. The second argument, then, is Relume's only remaining argument against a finding of obviousness as to claim 2. That argument is this: even if left unrebutted, Professor Erickson's third declaration does not establish obviousness because 1) he "never even states that the asserted claims would have been obvious at the time of the invention"; and 2) he generally fails to state the motivation for combining relevant prior art. **[**104]** (Pl.'s Obviousness Opp. Mot. at 23-24.)

The first criticism is baseless. With respect to his third declaration, Professor Erickson states in his third supplemental declaration that "all of my opinions concerning obviousness were made from the point of view of a person of ordinary skill in the art as of the time of the inventions of the *'645* and *'909 patents*, that is, as of the mid 1990's." (Third Suppl. Erickson Decl. at P 61.)

The second criticism is likewise baseless. Professor Erickson is careful throughout both of his obviousness declarations to explain what motivation, suggestion, or incentive in the relevant prior art would have made a combination obvious to one of ordinary skill in the art at the time of the invention at issue. In fact, Relume's criticism reveals a flaw in its own strategy in defending against Lumileds' obviousness challenges. Relume would have me treat the obviousness test with the stringency of an anticipation test, permitting no combinations to ever invalidate an invention as obvious simply because they are combinations.

In this vein, Relume accuses Professor Erickson of repeatedly using only the level of knowledge of one of ordinary skill in the art to **[**105]** supply missing suggestions to combine. Relume believes his declaration offends *Al-Site, supra,* in which the Federal Circuit reaffirmed the fundamental principle that skill in the art will rarely operate to supply missing knowledge or prior art to reach an obviousness judgment. See *174 F.3d at 1324.* As the court further explained, "skill in the art does not act as a bridge over gaps in substantive presentation of an obviousness case, but instead supplies the primary guarantee of objectivity in the process." Id.

While I of course heed the warning of Al-Site, I nevertheless find that its concern is inapplicable to the facts of this case. First of all, nearly all of the prior art at issue in Al-Site had been presented to the patent examiner by the patentee; the Federal Circuit observed that this made the obviousness burden more difficult to overcome. See *id. at 1323-24.* Here, in contrast, some of the most important prior art was not before the patent examiner, as indicated by my anticipation holdings. Thus Lumileds' burden is more easily overcome. See *Para-Ordnance Mfg. Inc. v. SGS Importers Int'l Inc., 73 F.3d 1085, 1088-89 (Fed. Cir. 1995),* **[**106]** cert. denied, *519 U.S. 822, 136 L. Ed. 2d 38, 117 S. Ct. 80 (1996).* Second, it is important **[*823]** to note that Al-Site's caution does not apply when the prior art references themselves provide some explicit or implicit motivation, suggestion, or incentive for combination. See *Al-Site, 174 F.3d at 1324.* As will become clear, the prior art references at issue in this case provide their own suggestions and incentives for combination. And, third, the court in Al-Site noted that the evidence against the asserted combination was substantial. See id. That is not the case here.

The first good example of the inapplicability of Al-Site is Lumileds' obviousness challenge to claim 2 of the *'645 patent.* The interesting fact about the Johnson patent, and why it is so damaging to the validity of Relume's *'645 patent*, is that it is itself already a combination. It wed the art of power supply electronics -- in particular, the art of switching power supplies (as explained in the Power Supply Cookbook) -- to the art of retrofit LED arrays for the benefit of efficient, long-lasting illumination. This is undisputed (and also why Johnson anticipates claim **[**107]** 1). Also undisputed is the fact that inherent in the use of switching power supplies at that time was the knowledge that only

three configurations existed: buck, boost, and buck/boost. Thus by teaching a switching power supply, the Johnson patent would have implicitly suggested to one of ordinary skill in the art the possibility of using a buck/boost switchmode converter for its power supply. This is all that Professor Erickson's opinion seeks to explain. Thus I find his unrebutted opinion regarding claim 2 to be clear and convincing evidence of the obviousness of that claim. I also find the relevant prior art references -- the Johnson patent and the Power Supply Cookbook in particular -- to be clear and convincing evidence, on their own, of the obviousness of claim 2.

Lumileds also argues that there is no difference for obviousness purposes between claim 4 of the *'645 patent* and the Johnson patent. Claim 4 recites the additional limitation of an EMI filter. Relume again has the same two flawed arguments in response. It does not submit evidence to rebut the evidence of the prior art references or Professor Erickson's opinion. Erickson concludes that the Johnson patent would have **[**108]** made the invention of claim 4 obvious to one of ordinary skill in the art because, among other things, the data sheet for the MC 34261 Motorola controller recommended by Johnson describes using an EMI filter. (See Third Erickson Decl. at PP 21-25.) Erickson points out that "every power supply circuit shown in the data sheet with the MC 34261 includes an EMI filter." (*Id. at P 23.*) Erickson also notes that the Power Supply Cookbook taught the crucial nature of EMI filters for switching power supplies; so it states that "the EMI filter is an integral part of any PFC [power factor correction] circuit." (*Id. at P 22.*)

I find all of this undisputed evidence to be clear and convincing evidence of the obviousness of claim 4 in light of Johnson and the Motorola data sheet. By recommending the use of the MC 34261 Motorola controller in its switching power supply, the Johnson patent implicitly suggests to one of ordinary skill in the art that the information in the controller's data sheet is useful and suitable for the operation of its invention. That information includes a strong teaching to use EMI filters with switching power supplies. Thus I find the Johnson patent is **[**109]** no different than the invention of claim 4 for purposes of obviousness because it suggests a combination of its explicit teachings -- the rectifier, the power factor correcting switching power supply, and the LED array -- with the EMI filter teaching of the Motorola data sheet.

b. Claims 5 and 6 of the *'645 Patent*

Lumileds argues that the prior art Hildebrand patent's dynamic load circuit is identical, or at least equivalent, to the adaptive clamp circuit of claims 5 and 6. The Hildebrand circuit is directed to "attenuating the effects of leakage currents when a particular [traffic or pedestrian **[*824]** crossing] signal is switched to its off state." Hildebrand, 1:8-10. It is undisputed fact that the Hildebrand circuit uses a Zener diode (CR5) in combination with a transistor (Q2) and that those components correspond to the Zener diode (D5) and the transistor (Q1) of the '645 clamp circuit's "voltage sensing means." Hildebrand, 5:57-65. It is also undisputed fact that the Hildebrand circuit uses a transistor (Q3) in combination with a resistor (R7) and that those components correspond to the transistor (Q2) and the resistor (R5) of the '645 clamp circuit's "control load means." Hildebrand, **[**110]** 5:66 to 6:6. Finally, it is undisputed fact that the Hildebrand circuit places resistor (R7) of its "control load means" in the circuit when the traffic light is off, thereby preventing leakage current, and that it completely removes this resistor (R7) from the circuit when the light is on. Hildebrand, 6:17-52. This operation corresponds to that of the '645 clamp circuit, which places the resistor (R5) of its "control load means" in the circuit when the light is off and then completely removes that resistor (R5) from the circuit when the light is on. '645, 7:53 to 8:1.

This undisputed evidence suffices to show that the Hildebrand device is nearly identical in structure and function to the adaptive clamp circuit of claims 5 and 6. First of all, it shows that the Hildebrand device "clamps" within the meaning of the *'645 patent.* [34] That is, when voltage falls below a certain amount -- the zener voltage of Hildebrand's Zener diode (CR5) -- that diode does not conduct and the leakage current is directed through resistor (R7). Hildebrand, 6:23. Likewise, when the '645's voltage falls below a certain amount -- the zener voltage of its Zener diode (D5) -- that diode does not conduct and **[**111]** leakage current is directed through resistor (R5). '645, 7:59-62. Second, the undisputed evidence also shows that the Hildebrand device is "adaptive" within the meaning of the *'645 patent.* When the Hildebrand light is on, its dynamic load circuit removes the resistor (R7), and when its light is off, it places the resistor (R7) in the circuit to clamp leakage. Hildebrand, 6:42-50; (Third Erickson Decl. at PP 33-34).

34 Relume argues that Hildebrand does not "clamp" within the meaning of the *'645 patent* because it does not do so at the zener voltage threshold of 40 volts -- an amount the '645 specification mentions (but does not require). I do not find this to be a substantial difference for obviousness purposes, however, because the specification statements in question do not suggest that the function of clamping cannot occur at different zener voltage thresholds.

In response to this overwhelming evidence of similarity, Relume first argues that the Hildebrand dynamic load circuit substantially differs from '645's [**112] adaptive clamp circuit because the Hildebrand transistor Q3 is not a solid state switch, as required by the *'645 patent*, but instead is a linear amplifier. Relume's argument relies on the opinion of its expert, Mr. Gafford. I do not find that its argument precludes summary judgment, however. Hildebrand does not call the transistor Q3 a "linear amplifier." Gafford bases his opinion solely on his conclusory observation that some of the language of the Hildebrand patent is "unique to the language of amplifiers." (Gafford Decl. at P 28.) Gafford does not explain how or why this is so.

Throwing further doubt on Gafford's reliability, Lumileds offers evidence showing that all switches, including Hildebrand's, operate in a linear amplifier mode for a period of milliseconds as they switch between on and off -- yet those in the art still consider them to be switches. (See Third Suppl. Erickson Decl. at P 63.) Thus I find that Gafford's opinion fails to set forth specific facts sufficient to raise a genuine issue of material fact. See *Lockwood v. American Airlines, Inc., 107 F.3d 1565, 1571 (Fed. Cir. 1997)* (finding that expert's conclusion that prior art patent claimed [**113] a limited structure did not preclude summary [*825] judgment when the patent's written description appeared to contradict his conclusion).

Relume's second argument in the face of Lumileds' evidence of structural and functional similarity is that the combination of Hildebrand's circuit and the Johnson device would be inefficient, thereby rebutting any motivation for combination. Relume's inefficiency argument relies on tests performed by Hochstein on a dynamic load circuit he built to match that taught in Hildebrand. Hochstein found that the circuit's power factor, harmonic distortion, and power dissipation characteristics would not pass ITE or Caltrans specifications for LED traffic signals. (See Hochstein Reply Decl. at PP 14-16.)

Even viewed in a light most favorable to Relume, Hochstein's tests do not constitute evidence that shows that the Hildebrand and Johnson devices are inefficient when operated *together*. All Hochstein's tests establish is the unsurprising fact that the Hildebrand device *alone* would not win the approval of industry specifications that apply to an entire power factor corrected, voltage-regulated LED power supply. The relevant tests for obviousness purposes [**114] would have been to test and compare the performance of Hildebrand's circuit against that of the '645's adaptive clamp circuit or, even better, to test and compare the performance of a combined Hildebrand and Johnson device against that of the entire invention of claims 5 or 6. Relume does not submit evidence of either.

Moreover, Lumileds is correct to point out that the claims of the *'645 patent* do not recite any values for power factor, harmonic distortion, or power dissipation. As the Federal Circuit has stated "the name of the game is the claim." *In re Hiniker, Co., 150 F.3d 1362, 1369 (Fed. Cir. 1998)* (upholding rejection for obviousness even though prior art performed less efficiently than patent's device because it refused to read specification's operational characteristics into broader claims). Accordingly, even if the efficiency of the Hildebrand circuit were to be less than that of the '645's adaptive clamp circuit (or the efficiency of Hildebrand/Johnson were less than that of claim 5 or 6), it would be irrelevant to the obviousness question before me.

This is particularly true in this case because a person of ordinary skill in the art would have had a strong [**115] motivation to combine Hildebrand and Johnson at the time of claim 5 and 6's invention. Hildebrand teaches the crucial lesson that retrofit bulbs in safety critical traffic or pedestrian crossing signals will create leakage current problems that could interfere with the conflict monitors. Hildebrand, 1:6-41. Thus Hildebrand would have motivated a person of ordinary skill in the art to combine its dynamic load circuit with the retrofit lamp of Johnson in order to prevent these well-known leakage current problems.

Accordingly, I find that the combination of the prior art Hildebrand and Johnson patents constitutes clear and convincing evidence of the obviousness of claims 5 and 6

of the *'645 patent* at the time of their invention. Relume's insufficient evidence fails to demonstrate a need for trial on the factual issue of the structural and functional similarity of a combined Hildebrand/Johnson device to claims 5 and 6. See *Liberty Lobby, 477 U.S. at 249-50.*

c. Claims 6 and 15 of the *'909 Patent*

Lumileds argues that a prior art combination -- the Fujitsu publication with one or both power supply textbooks -- is identical to claims 6 and 15 of the *'909 patent.* Claims **[**116]** 6 and 15 recite the alternate technique for adjusting the energy supplied to the LEDs by frequency modulation (instead of pulse width modulation). Fujitsu discloses pulse width modulation, but not frequency modulation. Both the Power Supply Cookbook and the Electronic Circuits and Applications disclose the use of frequency modulation with switching **[*826]** power supplies. Based on these sources and his expertise, Professor Erickson states in his declaration that the two methods were well-known design choices within the field of switching powers supplies. (See Third Erickson Decl. at PP 50-53.) Indeed, the *'909 patent* concedes this fact of the prior art when it notes that it is "widely recognized that control of power supply output voltage or output current is most efficiently accomplished by varying the pulse width or frequency of the switched waveform." '909, 5:51-54. From this evidence, then, it is clear that the Fujitsu publication would have suggested the alternate use of frequency modulation to one of ordinary skill simply because it used a switching power supply to adjust the average current to the LEDs.

Relume provides no specific facts in response. It reiterates conclusory **[**117]** denials that it also raised in the anticipation inquiry. Pursuant to *Rule 56(e),* this does not suffice to create a genuine dispute worthy of trial. I therefore find that the Fujitsu publication in combination with either power supply textbook constitutes clear and convincing evidence of obviousness because the combinations are no different from the inventions of claims 6 and 15.

d. Claims 9 and 18 of the *'909 Patent*

Lumileds argues that a prior art combination -- the Fujitsu publication with the Power Supply Cookbook -- is identical to the inventions of claims 9 and 18 of the *'909 patent.* Claims 9 and 18 relate to using a filter to provide substantially d.c. power to the LEDs. The Power Supply Cookbook establishes that it was well known in the art of the mid-1990's that a filter could be used to convert on/off pulses from a switching power supply to substantially d.c. power. The *'909 patent* acknowledges that d.c. power supplies "normally" use a filter to produce substantially d.c. power. '909, 4:54-56. And it is undisputed that the Fujitsu lighting control circuit is a d.c. power supply of the type referred to in the *'909 patent.* (See Third Suppl. Erickson Decl. **[**118]** at P 68.) Thus the evidence offered by Lumileds more than satisfies its *Rule 56(c)* burden of showing that there is no genuine issue of material fact that a combination of the Fujitsu publication and the Power Supply Cookbook is clear and convincing evidence of the obviousness of claims 9 and 18 at the time of their invention.

Relume's only defense is that Fujitsu teaches away from using a filter. Specifically, Relume argues that the Fujitsu circuit would not use a filter because it is well known in the optical scanning arts that the detector circuit must receive pulsed light from the LEDs for its efficient operation -- not the substantially constant light that would come from filtered, substantially d.c. power. Relume's only evidence in support of this argument comes from its inventor, Mr. Hochstein. (See Hochstein Reply Decl. at P 9.)

I find that Relume's argument fails to create a genuine issue of material fact. It depends on an erroneously narrow view of the invention disclosed by the Fujitsu publication. Although Fujitsu mentions application of its invention in the field of optical scanning devices, its claim language and written description are broad in scope and reveal **[**119]** an invention that could have application in any setting where LEDs are exposed to increasing temperatures. Furthermore, Fujitsu nowhere discloses the use of a pulse detector with its circuit. Nor does Relume submit any prior art references that support Hochstein's assertion about the ordinary knowledge of those in the optical scanning arts.

The Fujitsu publication simply lacks any express or implied teaching away from the use of a filter to produce substantially d.c. power. In fact, the evidence offered by Lumileds establishes that the Fujitsu publication would have suggested the use of a filter to one of ordinary skill given the fact that it is a d.c. powered device. I therefore find that the combination of Fujitsu and the Power Supply Cookbook constitutes clear and convincing evidence of obviousness **[*827]** because there is no difference between the combined prior art and the

inventions of claims 9 and 18.

4. Secondary Considerations

This final Graham inquiry requires me to consider relevant evidence of any secondary, non-obviousness factors such as commercial success, long-felt need, failure of others, skepticism and unexpected results. See 3 *M v. Johnson & Johnson Orthopaedics, Inc., 976 F.2d 1559, 1573 (Fed. Cir. 1992).* **[**120]** These secondary considerations, however, "are but a part of the 'totality of the evidence' that is used to reach the ultimate conclusion of obviousness." *Richardson-Vicks, 122 F.3d at 1483.* The existence of such evidence does not control the obviousness determination. Id.; see also *Ryko Mfg. Co. v. Nu-Star, Inc., 950 F.2d 714, 719 (Fed. Cir. 1991)* (noting that the weight of secondary considerations may be of insufficient weight to override a determination of obviousness based on primary considerations).

Relume makes various assertions and submits a smattering of anecdotal evidence as to four secondary considerations: copying, commercial success, long-felt need, and failure of others or skepticism. Each hinges on Relume's unstated assumption that all LED traffic lights which meet industry specifications must infringe the *'645* and *'909 patents*. As defendants' successful motions for noninfringement have demonstrated, however, there are many ways to satisfy industry specifications without using literally infringing technology. Even Hochstein concedes this. (See Hochstein Dep. at 455-56.)

I find Relume's arguments as to the copying factor to be without **[**121]** evidentiary support. Except for Ecolux's temperature compensation circuit, I found that all the accused products at issue in the motions did not literally infringe the asserted claims of the *'645* and *'909 patents*. Furthermore, Relume has no independent evidence of copying, only the assertion that because defendants at one point argued an equitable estoppel defense, they admit they copied Relume's patents. This assertion is of course insufficient to preclude summary judgment in the face of defendants' strong prima facie evidence of obviousness.

The commercial success factor is likewise unhelpful for Relume. Relume argues that evidence of defendants' commercial success, as well as its own, is evidence of the non-obviousness of its patents. This argument fails for two simple reasons. First, because Relume has failed to defeat defendants' motions for non-infringement (except with respect to Ecolux and the *'909 patent*), it cannot rely on the well-substantiated success of defendants' accused products to prove the commercial success of its claimed features. Second, Relume has not shown that its claimed features have enjoyed any commercial success. All it has proved to date is that one community **[**122]** -- Murietta, California -- has awarded it a bid for 400 LED traffic signals.

As to long-felt need, the only evidence Relume offers is evidence of a need for industry specifications, not necessarily for the claimed features of Relume's patents. Because defendants have demonstrated that there are several ways manufacturers can meet those specifications, Relume cannot rely on those specifications to establish that there was a long-felt need for its patents. At best, Relume's evidence suggests that the LED traffic signal industry began in the last few years to regulate itself.

The final factor Relume argues is failure of others or skepticism. Its evidence of this is slim to non-existent. It first offers the testimony of Patrick Mullins, an individual associated with McCain Traffic Supply, as evidence of failure. (See Mullins Dep. at 40-41, 80.) Relume claims that he testifies as to McCain's inability to make an LED traffic signal with power factor correction. A close reading of Mullins' testimony, however, reveals that he only states that McCain never successfully marketed an **[*828]** LED traffic signal with power factor correction, not that it could not build one. (See *id. at 80.*) Relume **[**123]** also offers the testimony of a Martin Wallen as evidence of skepticism as to the *'909 patent*. Wallen's testimony alone does not constitute sufficient evidence to overcome the strong prima facie evidence of obviousness in this case.

In the end, Relume cannot point to any convincing evidence of non-obviousness. In light of the clear and convincing prima facie evidence of obviousness in the prior art, I therefore hold that claims 2, 4, 5, and 6 of the *'645 patent* and claims 6, 9, 15, and 18 of the *'909 patent* are invalid because they would have been obvious to one of ordinary skill in the art at the time of their invention.

Conclusion

For all of the foregoing reasons, Dialight's, Precision's, and Lumileds' motions for noninfringement are **GRANTED** on the issue of literal noninfringement as to all asserted claims of the *'645* and *'909 patents*.

Ecolux's motion for noninfringement is **GRANTED** on the issue of literal noninfringement as to all asserted claims of the *'645 patent*, but is **DENIED** on the same issue as to the asserted claims of the *'909 patent*.

I decline to consider the issue of infringement through the doctrine of equivalents at this time because of the **[**124]** parties' inadequate briefing on that issue. This has no bearing on the outcome of the case, however, because of my validity rulings, which find all asserted claims invalid due to prior art.

Accordingly, Lumileds' anticipation motion is **GRANTED** as to claim 1 of the *'645 patent* and claims 1-3, 7, 10-12, and 16 of the *'909 patent*, but is **DENIED** as to claims 2 and 4 of the *'645 patent*. Lumileds' obviousness motion is **GRANTED** as to claims 2, 4, 5, and 6 of the *'645 patent* and claims 6, 9, 15, and 18 of the *'909 patent*.

IT IS SO ORDERED.

John Feikens

United States District Judge

DATED: Aug 26, 1999

RELUME CORPORATION, Plaintiff-Appellant, v. DIALIGHT CORPORATION, ECOLUX, INC., and PRECISION SOLAR CONTROLS, INC., Defendants, and LUMILEDS LIGHTING BV, PHILIPS LIGHTING BV, and HEWLETT-PACKARD COMPANY, Defendants-Cross Appellants.

00-1164, 00-1180

UNITED STATES COURT OF APPEALS FOR THE FEDERAL CIRCUIT

4 Fed. Appx. 893; *2001 U.S. App. LEXIS 2045*

February 8, 2001, Decided

NOTICE: [**1] RULES OF THE FEDERAL CIRCUIT COURT OF APPEALS MAY LIMIT CITATION TO UNPUBLISHED OPINIONS. PLEASE REFER TO THE RULES OF THE UNITED STATES COURT OF APPEALS FOR THIS CIRCUIT.

SUBSEQUENT HISTORY: Rehearing Denied March 6, 2001, Reported at: *2001 U.S. App. LEXIS 4466*.

DISPOSITION: Affirmed.

JUDGES: Before CLEVENGER, SCHALL, and BRYSON, Circuit Judges.

OPINION BY: CLEVENGER

OPINION

[*894] CLEVENGER, *Circuit Judge*.

Relume Corporation ("Relume") appeals from the summary judgment of the United States District Court for the Eastern District of Michigan, holding that the defendants' accused products do not literally infringe the asserted claims of *U.S. Patent No. 5,661,645 ("the '645 patent")* or *U.S. Patent No. 5,783,909 ("the '909 patent")*, both assigned to Relume, and holding that both patents are invalid. *Relume Corp. v. Dialight Corp., 63 F. Supp. 2d 788, 802 (E.D. Mich. 1999)*. We *affirm*.

I

Relume raises several arguments on appeal: (1) whether the district court erred in its interpretation of certain limitations in the patents, (2) whether such errors in claim interpretation led to errors in the court's analysis of the validity issues, (3) whether disputed issues of material fact preclude summary judgment on the validity issues, and (4) whether alleged errors in claim interpretation [**2] or the disputed issues of material fact undercut the district court's judgment of no literal infringement.

II

We have fully reviewed the careful, extensive and well-crafted opinion of the district court. We have carefully examined the arguments presented by the parties in their briefs and have considered in full the arguments made by the parties at oral argument.

For the reasons stated in the opinion of the district court, we agree that all of the asserted claims of the *'645* and *'909 patents* are invalid. Because we affirm the district court's judgment on the validity issues, we need not reach the questions raised by Relume as to the judgment of noninfringement.